LEVEL III

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USER'S MANUAL FOR SOLID PROPULSION OPTIMIZATION CODE (SPOC)

Volume II - User's ~~Code~~

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Prepared for

AIR FORCE ROCKET PROPULSION LABORATORY
DIRECTOR OF SCIENCE AND TECHNOLOGY
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FOREWORD

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This report is Volume II of a three-volume user's manual for a computer code that performs detailed preliminary designs of solid propellant rocket motors. All major components and performance of a motor are mathematically determined using source dimensions and characteristics. A direct pattern search nonlinear optimization scheme based on the Hooke and Jeeves algorithm is employed to establish motor characteristics that optimize any one of several performance parameters. Decision

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20. variables during optimization are propellant formulation, propellant burn rate, propellant grain dimensions, nozzle dimensions, and pressure vessel dimensions. Provisions are made for easily inserted user-defined models of several characteristics. Constraints imposed during the optimization process are performance requirements, design constraints, and operating limits.

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VOLUME II
USER'S GUIDE

INTRODUCTION

The Solid Propulsion Optimization Code (SPOC) performs detailed preliminary designs of a large variety of solid propellant rocket motors. Dimensions of the propellant grain, nozzle, and pressure vessel are adjusted by the code, along with propellant formulation and burn rate, to produce a motor design that satisfies performance requirements and design constraints, and that has been optimized with respect to a user-selected parameter.

This volume of the User's Manual - Volume II, User's Guide - contains the input and output dictionaries and ~~their accompanying~~ illustrations, along with other input instructions that are needed to execute the code. Volume I (Technical Description) gives the basis for the code computation, analytical developments, logic flow charts used in verification checks and error messages. Volume III (Program Description) contains the subroutine descriptions and flow charts, cross indices of common statements, subroutines and call statements.

The user supplies a starting condition---an initial design---and all associated information needed to evaluate that design. These data are read in through a series of input namelists. The initial design is evaluated in the executive subroutine COMP and the results are printed. Then the print control is turned off[1] and optimizer routine (PATSH) is called, which in turn makes multiple calls to COMP to evaluate the design with PATSH-generated changes in values of user-specified parameters. Once an optimized design[2] is reached, the print control is turned on and a final pass through COMP gives a complete description of the final design.

The analyses performed in SPOC are:

(1) Grain geometric validation
(2) Nozzle geometric validation
(3) Propellant thermochemistry

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(1) There is a control that specifies a complete print-out of all design analyses for each pass through COMP, which is useful for determining why a search is behaving as it does, but which produces a great deal of printout.

(2) An "optimized design" is reached when (1) no further improvement in the objective function is realized; (2) the number of base points defined in the search equals an input limit; (3) the pattern search step size becomes less than an input minimum. Any one of these three conditions will trigger a return to COMP for the final evaluation.

(4) Ballistic simulation
(5) Nozzle erosion, char and thermal penetration prediction
(6) Case structural
(7) Propellant structural
(8) Trajectory simulation
(9) Cost prediction
(10) Combustion stability prediction

ORGANIZATION OF USER'S GUIDE

This volume of the User's Manual is arranged in the same order as is the printed output, which corresponds to the order in which the input namelists must be read. The basic mode of code operation is to:

(1) Read an input namelist (on the first pass through COMP), or,

(2) On subsequent passes, accept from PATSH values for those parameters being adjusted in the pattern search that "belong" to this namelist.

(3) Perform verification calculations on the current set of inputs. Use the inputs to generate data needed for subsequent analyses (e.g., propellant grain dimensions for ballistic simulation, valid propellant formulation for thermochemical analyses, etc.). Print all results (on first and last passes through COMP).

(4) Repeat (1), (2) and (3) until all data is obtained for a particular subsequent analysis. For example, many input sets and intermediate analyses are needed before the ballistic simulation can be performed.

(5) Perform various performance and design analyses, reading in required data as needed.

Thus, in the following sections, descriptions of input are interspersed with descriptions of outputs, along with the appropriate illustrations. The order of the presentation in this manual is the same as the order of input and output listed by the code.

ORDER OF INPUTS

The input namelists must be entered exactly as shown in Table 1. Three comment cards are available for run identification.

TABLE 1

ORDER OF INPUT DECK

Order of Input	Namelist Identification	Purpose of Input Block	Section of Manual
1	3 cards	Problem identification	n/a
2	CONTRL	Motor and problem definition	Problem Definition
3	GRAINi	Description of specified propellant grain (i=1, 2, 3, 4, or 5). Dimensions and densities of inert components. Designate searched parameters. For use in validating dimensions and setting up dimensions for ballistic simulation.	Grain Type 1 Grain Type 2 Grain Type 3 Grain Type 4 Grain Type 5
4	NOZGEO	Nozzle dimensions	Nozzle Inputs
5	NOZMTL	Nozzle material characteristics	
6	NOZHT	Nozzle heat transfer parameters	
7	BALLST	Describes ballistic characteristics of motor and propellant	Ballistic Inputs
8	1-4 cards	Thermochemical properties of one to four propellant ingredients not stored in code dictionary.	
9	1 card	Propellant identification	Thermochemistry
10	1 card	Identifies generic names of propellant ingredients with a particular constituent	
11	INGAMT	Weight fraction and propellant ingredients	
12	INGFIX	Specifies which ingredient weight fractions will be adjusted during optimization	
13	INGLIM	Limits on ingredient weight fraction imposed during optimization	

Table 1

ORDER OF INPUT DECK (contd.)

Order of Input	Namelist Identification	Purpose of Input Block	Section of Manual
14	REQMTS	Performance requirements, design constraints, operating limits	Requirements and Constraints
15	CASE	Pressure vessel mechanical properties for use in case structural analysis	Case Structural
16	STPROP	Propellant physical and thermal properties for use in propellant structural analysis	Propellant Structural
17	CTRAJ	Controls for trajectory simulation	Trajectory Simulation
18	LAUNCH	Launch conditions for trajectory simulation	
19	AERO	Aerodynamic data for trajectory simulation	
20	TERM	Termination commands for trajectory simulation	
21	CSTINP	Cost analysis inputs	Cost Analysis
22	STABIN	Inputs for combustion stability analysis	Combustion Stability

MOTOR AND PROBLEM DEFINITION

This block of input data contains the commands that describe the motor and problem. All data are contained in a single namelist CONTRL. There is no output other than self-explanatory notes.

The user must make the following basic choices to define the motor configuration.

Any conbination of grain, closure and nozzle may be selected except that the Type 4 grain (conocyl) may be used only with the Type 1 forward closure.

Propellant Grain: choose one from those illustrated in Figure 1

- Type 1: Star
- Type 2: Double-web wagon wheel
- Type 3: Finocyl (slots in forward end)
- Type 4: Conocyl
- Type 5: Cylindrically perforated (CP)

Nozzle: choose one from those illustrated in Figure 2

- Type 1: Thin shell, composite structure as the insulating ablative and support structure.
- Type 2: Thin shell support structure with insert and ablative insulator.
- Type 3: One-piece ablative; supersonic blast tube; constant diameter support structure.
- Type 4: One-piece ablative; supersonic blast tube; reduced diameter aft section.
- Type 5: Subsonic blast tube; without expansion section.
- Type 6: Subsonic blast tube; with expansion section.

Forward Closure: choose one from those illustrated in Figure 3

- Type 1: Ellipsoidal
- Type 2: Flat plate with closure secured with retaining ring
- Type 3: Flat plate with closure integral with case

Aft Closure: choose one from those illustrated in Figure 4

- Type 1: Ellipsoidal
- Type 2: None (aft closure formed by nozzle entrance section)

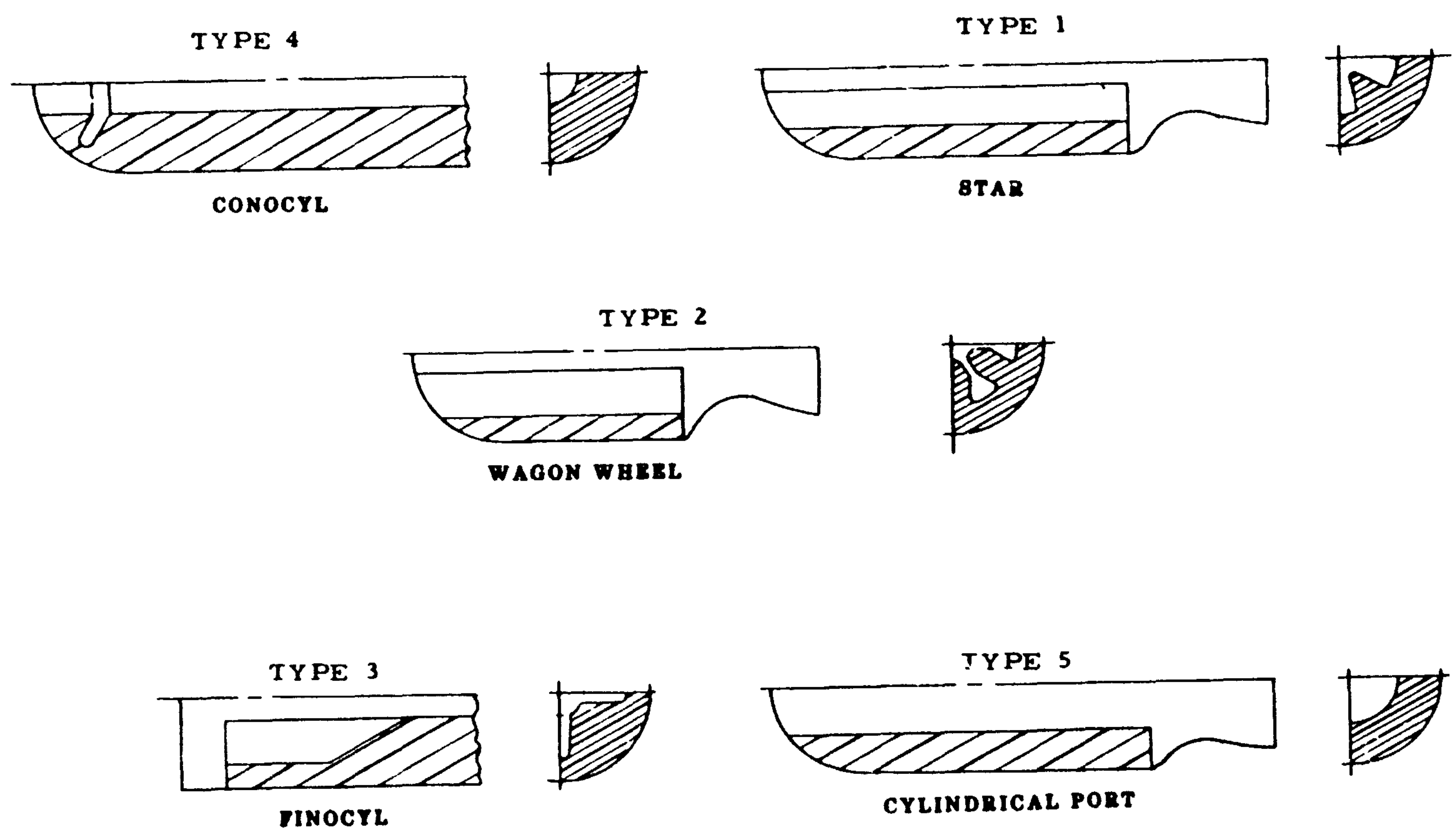
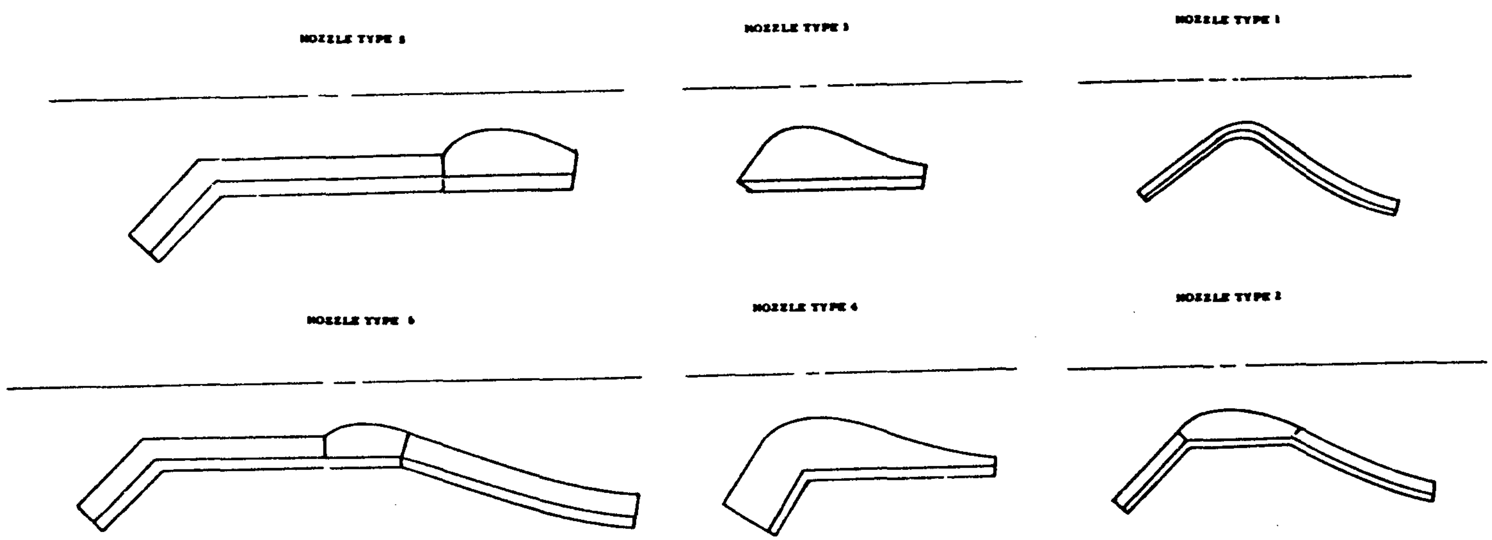
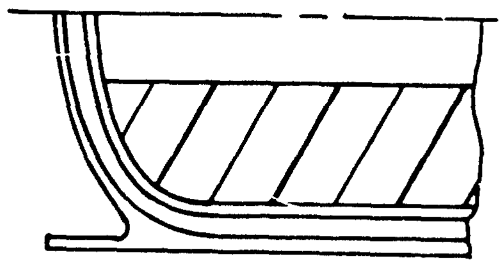


Figure 1. Propellant Grain Geometries Available in SPOC

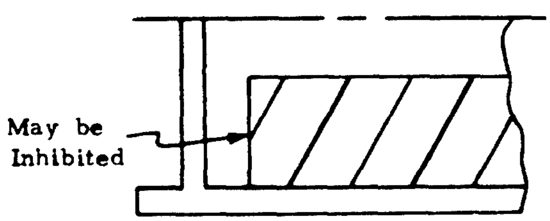


All Exit Sections May be Conical or Contoured

Figure 2. Nozzle Configurations Available in SPOC

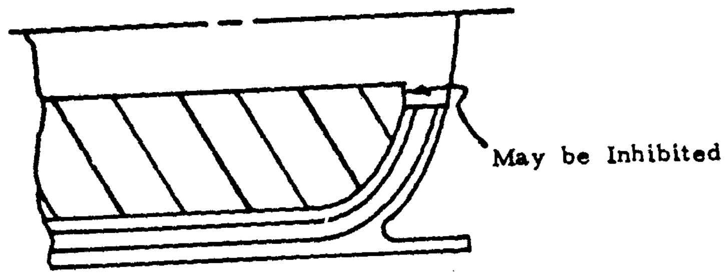


Ellipsoidal - Type 1

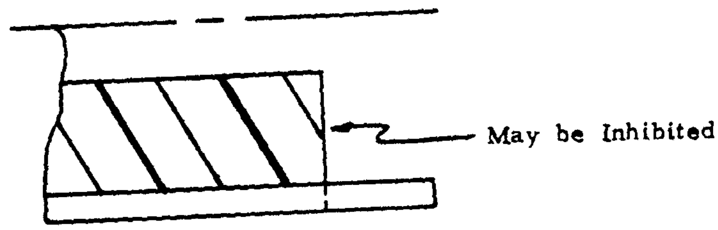


Flat Plate - Type 2 (Retaining Ring)
Type 3 (Integral with Case)

Figure 3. Forward Closure Configuration Available in SPOC



Ellipsoidal - Type 1



None - Type 2 (Formed by Nozzle)

Figure 4. Aft Closure Configurations Available in SPOC

Other choices that must be made to define the problem are:

1. A propellant formulation may be input and adjusted as part of the optimization (FORMAD=T), in which case the thermochemistry routines are entered every time the design is evaluated (except for some internal bypasses to reduce execution time). Another option is to input a formulation but not adjust it (FORMIN=T), in which case the thermochemistry routines are entered only for the first evaluation in order to obtain basic propellant characteristics for the ballistic simulation. The third option is for the user to input the appropriate ballistic parameters rather than having the thermochemistry routines calculate them from a formulation (PROPIN=T). The proper combination of these three inputs are shown below (all default to F).

MODE		FORMAD	FORMIN	PROPIN
(1)	Formulation input and adjusted during optimization	T	F	F
(2)	Formulation input, but not adjusted	F	T	F
(3)	User supplies required propellant characteristics	F	F	T

2. Impulse efficiency may be input by the user; calculated internally with the AFRPL SPP "empirical model", or calculated with a user-supplied model which he must install in subroutine USEREF. EFMDL=T is the flag to show a user model has been supplied. SPPETA=T is the flag to specify the SPP model.

3. Propellant burn rate is calculated internally with the Vielle model, or with a user-supplied model which he must install in subroutine USERRB. RBMDL=T is the flag to show a user model has been supplied.

4. The propellant face on the forward end of a grain with a Type 2 or Type 3 forward closure and on the aft face of a grain with either a Type 1 or Type 2 aft closure may be inhibited through use of FWDINH=T or AFTINH=T, respectively.

5. Ballistic simulations will be performed at both the low temperature and high temperature conditions if different values are input for THI and TLO. Propellant structural analysis is performed at a different temperature (TPROP) than is the low temperature ballistic simulation. Pressure vessel structural analysis is performed at the high temperature condition. If THI is input equal to TLO, only one ballistic simulation is performed; propellant structural analysis is still performed at TPROP. Pressure vessel structural analysis is performed with the results of the high-temperature ballistic simulation if two simulations are performed; if only one simulation is performed, the results are used without any temperature adjustment.

6. The optimization routine will adjust user-specified parameters in order to meet all performance requirements and satisfy all design constraints. In addition, the user may specify another parameter to be optimized by setting ICHOZE to one of the following

0: None (default value)
1: Minimize cost
2: Minimize total motor weight
3: Maximize total impulse
4: Maximize total impulse-to-total weight ratio
5: Maximize burnout velocity

An input SCALE is used as a multiplier to adjust the expected value of PAYOFF to about 2000, because each penalty is scaled to be about 10-20% of 2000.

7. A trajectory simulation (point mass, flat earth, ballistic trajectory) will be performed if specified by the user (FTRAJ=T). If ballistic simulations are performed at two temperatures (TLO and THI), then trajectory simulations are performed with each of the resultant thrust-time histories if certain inputs are included (see Trajectory section for details). In addition, the user must select a trajectory termination option.

8. There are 36 parameters (not all on one problem) whose values can be adjusted by the optimization routine PATSH to achieve an optimum design (Table 2). Each of these must be specified by the user as "T" (maintain at input value) or "F" (do not maintain at input value, but adjust during pattern search).

9. Motor cost will be calculated with the Tri-Services cost model or with a user-supplied model. FCOST=T is the flag to specify the Tri-Services model; CSTMDL is the flag to show a user-supplied model has been provided.

10. Either a contoured or conical nozzle exit section may be specified (CONTUR=T or CONTUR=F, respectively). If a conical exit section is selected, the initial half-angle (ALFA) must be input equal to the exit half-angle (ALFAEX).

11. Several analyses are by-passed completely unless the user specifies otherwise.

(a) Propellant structural analysis (PSTRUC=T)
(b) Combustion stability (FSTAB=T)
(c) Trajectory simulation (FTRAJ=T)
(d) SPP impulse efficiency (SPPETA=T)
(e) Thermochemistry (FORMAD=T or FORMIN=T)
(f) Cost (FCOST=T)

TABLE 2

ADJUSTABLE VARIABLES AVAILABLE IN SPOC

Variable Number	Value of Variable: Variable Name	Value of Variable: Input Source (1)	Search Control: Control Name	Search Control: Input Source (1)	Definition
1	BIND	INGAMT	FBIND	INGFIX	Weight fraction of binder
2	FUEL	INGAMT	FFUEL	INGFIX	Weight fraction of fuel
3	OXA(1)	INGAMT	FOXA(1)	INGFIX	Weight fraction of oxidizer A, Size (1)
4	OXA(2)	INGAMT	FOXA(2)	INGFIX	Weight fraction of oxidizer A, Size (2)
5	OXA(3)	INGAMT	FOXA(3)	INGFIX	Weight fraction of oxidizer A, Size (3)
6	OXB(1)	INGAMT	FOXB(1)	INGFIX	Weight fraction of oxidizer B, Size (1)
7	OXB(2)	INGAMT	FOXB(2)	INGFIX	Weight fraction of oxidizer B, Size (2)
8	OXB(3)	INGAMT	FOXB(3)	INGFIX	Weight fraction of oxidizer B, Size (3)
9	RCATL	INGAMT	FRCL	INGFIX	Weight fraction of liquid rate catalyst
10	RCATS	INGAMT	FRCS	INGFIX	Weight fraction of solid rate catalyst
11	STAB	INGAMT	FSTAB	INGFIX	Weight fraction of combustion stabilizer
12	RE	NOZGEO	FDE	NOZGEO	Nozzle exit radius (Note 2)
13	RT	NOZGEO	FDTI	NOZGEO	Nozzle throat radius (Note 2)
14	R2A1	GRAIN3	FR2A1	GRAIN3	Propellant port radius at Plane 1 (Grain 3), and star point tip radius at Plane 1 (Grain 2)
15	R2A14	GRANIi	FR2A14	GRAINi	Propellant port radius at Plane 14 (Grains 3, 4, and 5)
16	R4A1	GRAIN3	FR4A1	GRAIN3	Propellant slot fillet radius at Plane 1 (Grain 3)
17	R5A1	GRAINi	FR5A1	GRAINi	Propellant slot depth radius at Plane 1 (Grain 3) and fillet radius between propellant tip and web (Grain 1 and 2)

(1) Namelist designation
(2) Input as appropriate diameter

Table 2

ADJUSTABLE VARIABLES AVAILABLE IN SPOC (contd.)

Variable Number	Value of Variable: Variable Name	Value of Variable: Input Source (1)	Search Control: Control Name	Search Control: Input Source (1)	Definition
18	ALPHA1	GRAINi	FALPA1	GRAINi	Angle on side of propellant slot (Grain 3), and included half-angle of start tip (Grain 1)
19	LSLOT	GRAIN3	FLSLOT	GRAIN3	Length of propellant slot (Grain 3)
20	LCP	GRAINi	FLCP	GRAINi	Length of cylindrically perforated grain section (Grains 3, 4, 5)
21	LCONE	GRAINi	FLCONE	GRAINi	Length of aft coned grain section (Grains 3, 4, 5)
22	ALFAEX	NOZGEO	FALFAX	NOZGEO	Nozzle exit half angle
23	TCASE	GRAINi	FTCASE	GRAINi	Case wall thickness, cylindrical section
24	RB70	BALLST	FRB70	BALLST	Propellant burn rate at 70°F, 1000 psia
25	XN	BALLST	FXN	BALLST	Pressure exponent in burn rate model
26	LCONEF	GRAIN5	FLCONF	GRAIN5	Length of forward coned grain section (Grain 5)
27	RMOTOR	GRAINi	FDMTR	GRAINi	Motor outside radius (Note 2)
28	R2A3	GRAIN4	FR2A3	GRAIN4	Propellant port radius at Plane 3 (Grain 4)
29	RTIP	GRAIN4	FRTIP	GRAIN4	Outboard radius of propellant slot (Grain 4)
30	ZED	GRAIN4	FZED	GRAIN4	Angle of slot with centerline (Grain 4)
31	LH	GRAIN4	FLH	GRAIN4	Length of forward propellant segment (Grain 4)
32	TAUW1	GRAINi	FTAUW1	GRAINi	Propellant web thickness (Grains 1 and 2)
33	LSA1	GRAINi	FLSA1	GRAINi	Star tip height at Plane 1 (Grains 1 and 2)
34	LSA14	GRAINi	FLSA14	GRAINi	Star tip height at Plane 14 (Grains 1 and 2)
35	LFWD	GRAINi	FLFWD	GRAINi	Length of forward untapered propellant section (Grains 1 and 2)
36	LTAPER	GRAINi	FLTAPR	GRAINi	Length of aft tapered propellant sections (Grains 1 and 2)
37	R2A5	GRAIN5	FR2A5	GRAIN5	Propellant port radius at Plane 5 (Grain 5)

12. The user may provide models for certain parameters that are used in the analyses. A flag is set to show a user model has been loaded into a specified subroutine (T=model has been supplied).

Flag	Load in Subroutine	Parameter to be Supplied
RBMDL	USERRB	Propellant burn rate, RATE (in/sec)
SEMDL	USERSE	Propellant nominal strain endurance, SENOM (in/in)
EOMMDL	USERRH	Propellant rheological property to be defined by user, EOM (units by user)
CSTMDL	USERCS	Motor cost, COST ($ or $/unit)
EFMDL	USEREF	Impulse efficiency, ETAISP (% x 0.01)
*	RSPNSE	Combustion re ponse

*IRSPNS = 5 in namelist STABIN

13. The user may supply thermochemical data for up to four propellant ingredients not presently stored in the code. A flag INGIN=T is required in namelist CONTRL and the data are input on a formated card.

TABLE 3

NAMELIST CONTRL

INPUTS TO DEFINE MOTOR AND PROBLEM

Parameter Name	Default Value	Definition and Units
AFTINH	F	Propellant face on aft end of grain (perpendicular to motor centerline) is inhibited (T = yes, F = no)
CONTUR	F	Contoured nozzle exit section is required (T = yes, F = no)
CSTMDL	F	Cost model is supplied by user (T = yes, F = no)
DEL	1.0	Starting step size multiplier for pattern search
DELMIN	0.01	Minimum step size multiplier, at which search is terminated
EFMDL	F	Impulse efficiency model is supplied by user (T = yes, F = no)
FCOST	F	Motor cost calculation is required, either by Tri-Services model or user-supplied model (T = yes, F = no)
FORMAD	F	Propellant formulation is input and is adjusted (T = yes, F = no)
FORMIN	F	Propellant formulation is input to obtain internal calculation of thermochemical properties (on first pass only), but formulation will not be adjusted (T = yes, F = no)
FTRAJ	F	Trajectory simulation is required (T = yes, F = no)
FWDINH	F	Propellant face on forward end of grain (perpendicular to motor centerline) is inhibited. Applies only to Forward Closure Type 2 and Type 3. (T = yes, F = no)
FSTAB	F	Combustion stability analysis is required (T = yes, F = no)
GRAIN	Note 1	Integer to specify propellant grain configuration 1: Star 2: Wagon wheel 3: Finocyl with forward slots 4: Conocyl 5: Cylindrically perforated port (CP)

Table 3

NAMELIST CONTRL (contd.)

Parameter Name	Default Value	Definition and Units
IAFTCL	Note 1	Integer to specify aft closure configuration 1: Ellipsoidal from case to nozzle joint 2: Aft closure formed by nozzle entrance
ICHOZE	0	Integer to specify optimization payoff parameter, which is added to external penalties to form objective function (OBJC) 0: None 1: Cost (minimize) 2: Total motor weight (minimize) 3: Total impulse, low temperature, lower three-sigma (maximize) 4: Impulse-to-weight ratio, low temperature, lower three-sigma (maximize) 5: Burnout velocity. Includes drag effects when calculated by trajectory subroutine. Ideal, drag-free when calculated by subroutine FLT (maximize)
IFWDCL	Note 1	Integer to specify forward closure configuration 1: Ellipsoidal 2: Flat plate with closure secured by retainer ring 3: Flat plate with closure integral with case
INGIN	F	User will input data for one or more ingredients that are not presently in BLDATA
IPRTI	0	Integer to specify when complete analysis description will be printed 0: Only for initial (starting) design and final (optimized) design 1: At every exploratory and pattern move
IPT	+1	Integer to specify amount of output from optimizer to be printed on first and last passes +1: Value of each adjusted parameter and objective function for all exploratory moves, pattern moves, and base points. 0: Value of each adjusted parameter and objective function at base points only -1: No printout

Table 3

NAMELIST CONTRL (contd.)

Parameter Name	Default Value	Definition and Units
ITLIM	100	Integer for maximum number of base point iterations allowed in search, after which search is terminated
NOZTYP	Note 1	Integer to specify nozzle type 1: Thin shell, composite ablative and structure 2: Thin shell support structure, with insert and ablative 3: One-piece ablative insert; supersonic blast tube; constant diameter support structure 4: One-piece ablative insert; supersonic blast tube; reduced diameter aft section 5: Subsonic blast tube, without expansion cone 6: Subsonic blast tube, with expansion cone
PROPIN	F	Propellant formulation is not input and user must supply thermochemical properties (T = yes, F = no)
PSTRUC	F	Propellant structural analysis is required (T = yes, F = no)
RBMDL	F	Propellant burn rate model is supplied by user (T = yes, F = no)
SPPETA	F Note 2	Impulse efficiency is calculated with AFRPL SPP "empirical model" (T = yes, F = no). Must input FORMAD = T or FORMIN = T if SPPETA = T is selected: otherwise certain inputs to SPP efficiency must be furnished by user (see note 5, Table 18).

NOTES

1. Input is required for all problems.
2. When SPPETA = F, user must supply value of ETAISP or a value of 0.95 will be used.

GRAIN TYPE 1 - STAR

This block of input data describes the standard star grain configuration and the forward and aft closures. All data are contained in a single namelist GRAIN1.

The closure inputs are included in the input block for each grain type. However, the illustrations of the closures that show common parameters are included only in this Type 1 description.

Input data are provided to a subroutine SETUP1 that (1) confirms the geometric validity of all the grain dimensions (e.g., PATSH-adjusted lengths greater than zero, initial grain dimensions "close" properly, etc); (2) checks dimensions against user-supplied limits (e.g., propellant web fraction less than limit, clearances between propellant and case greater than limit, etc.); (3) generates dimensions that describe propellant initial internal and external surfaces to the ballistic simulation module; (4) calculates all inert weights in the pressure vessel (except for pressure vessel closures, which is done after a design pressure is available from the ballistic simulation). The results of these analyses are given as part of this block of code output.

Dimensions describing the grain cross-section (R5A1, TAUW1, ALPHA1, LSA1, LSA14) can be held constant during an optimization by setting FTYP1 = T, or they can be adjusted by PATSH by setting FTYP1 = F.

TABLE 4

NAMELIST/GRAIN1

INPUTS FOR TYPE 1 GRAIN BALLISTIC SIMULATION

Parameter Name	Default Value	Definition and Units
ALPHA1	0.0	Included half-angle (deg) of star tip.
BETA2A	0.0 Note 2	Ellipse ratio (major/minor diameter) of inside surface of pressure vessel aft closure Type 1.
BETA2F	0.0 Note 2	Ellipse ratio (major/minor diameter) of inside surface of pressure vessel forward closure Type 1.
CLEAR	0.0	Radial clearance (in) between port radius and radius of aft closure opening on aft closure Type 1. Positive when port is smaller than opening.
DELAI	0.0	Density (lbm/cu in) of insulation to protect grain against aerodynamic heating.
DELCAS	0.0	Density (lbm/cu in) of pressure vessel (case cylindrical section and integral closures).
DELCLO	0.0	Density (lbm/cu in) of Type 2 forward closure.
DELINS	0.0	Density (lbm/cu in) of case internal insulation.
DELLNR	0.0	Density (lbm/cu in) of liner.
DELSRB	0.0	Density (lbm/cu in) of stress relief boot.
DMOTOR	Note 1	Outside diameter (in) of motor.
LFWD	Note 1	Length (in) of forward untapered portion of grain.
LTAPER	Note 1	Length (in) of aft tapered portion of grain.
LGAPF	0.0	Length (in) between forward face of grain and aft face of insulation on Forward Closure Types 2 or 3.
LIGN	0.0	Length (in) of igniter and/or safe-and-arm device that extends forward of the outside surface of the forward closure.
LSA1	Note 1	Height (in) of star tip at Plane 1, measured from web.
LSA14	Note 1	Height (in) of star tip at Plane 14, measured from web.

Table 4

INPUTS FOR TYPE 1 GRAIN BALLISTIC SIMULATION (contd.)

Parameter Name	Default Value	Definition and Units
LSKTA	0.0	Length (in) of aft thrust skirt.
LSKTF	0.0	Length (in) of forward thrust skirt.
NSLOTS	Note 1	Integer to specify number of star points in grain.
R2A1	0.0	Radius on star tip at Plane 1.
R5A1	0.0	Fillet radius (in) R5 at Plane 1 between star tip and web.
TAEROI	0.0	Thickness (in) of insulation to protect grain againt aerodynamic heating.
TAUW1	Note 1	Web thickness (in) at Plane 1
TCASE	Note 1	Thickness (in) of pressure vessel cylindrical section.
TFABC	0.0	Minimum allowed thickness (in) of case cylindrical section due to fabrication considerations.
TINAMN	0.0	Thickness (in) of insulation in aft closure Type 1, measured at tangent point of closure and case cylindrical section.
TINAMX	0.0	Thickness (in) of insulation in aft closure Type 1, measured at opening of closure (where nozzle attaches).
TINF	0.0	Thickness (in) of insulation on flat plate forward closures (Type 2 or Type 3).
TINFMN	0.0	Thickness (in) of insulation in forward closure Type 1, measured at tangent point of closure and case cylindrical section.
TINFMX	0.0	Thickness (in) of insulation in forward closure Type 1, measured at RIGN radius.
TINSUL	0.0	Thickness (in) of insulation. Constant over entire interior surface of cylindrical section.
TLNR	0.0	Thickness (in) of liner, constant over entire interior surface.
TSKTA	0.0	Thickness (in) of aft thrust skirt.

Table 4

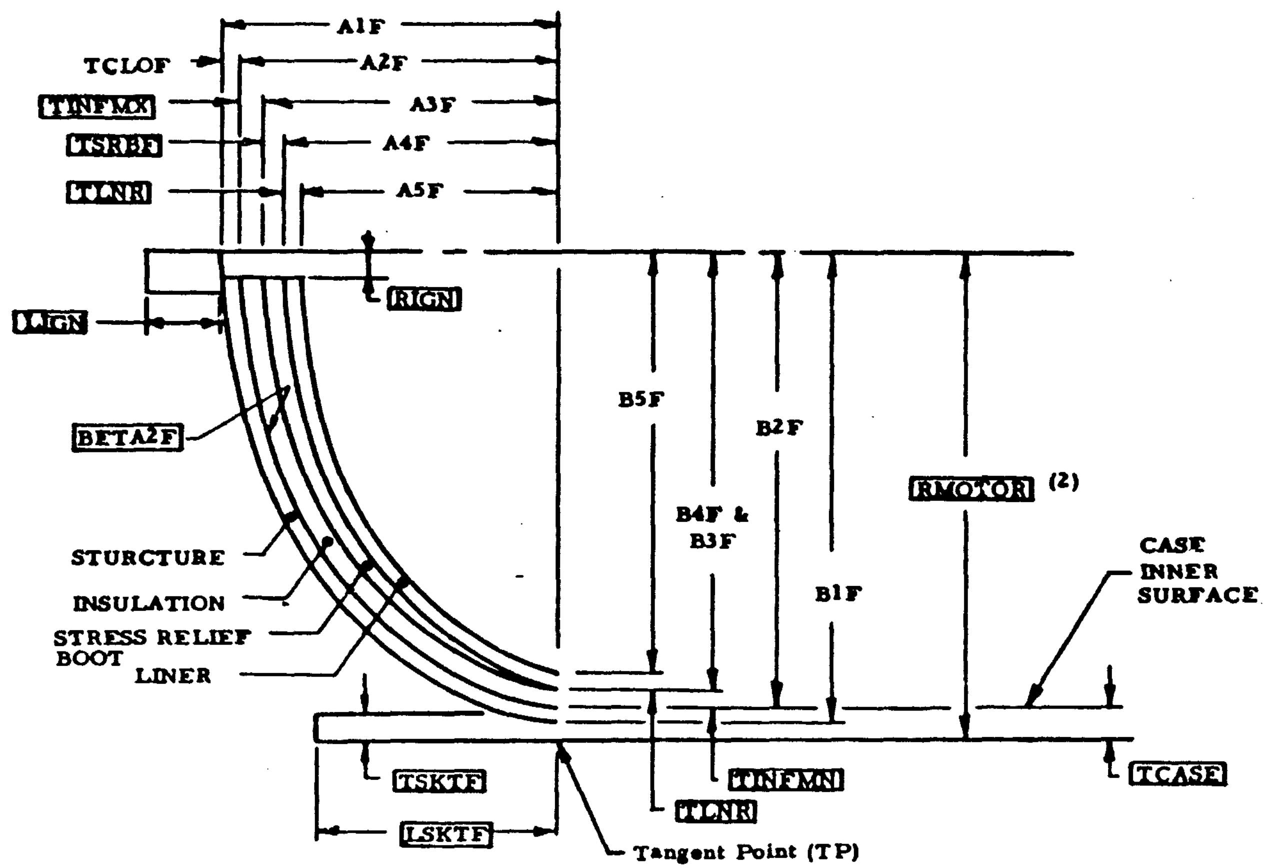
INPUTS FOR TYPE 1 GRAIN BALLISTIC SIMULATION (contd.)

Parameter Name	Default Value	Definition and Units
TSKTF	0.0	Thickness (in) of forward thrust skirt.
TSRBA	0.0	Thickness (in) of stress relief boot in aft closure Type 1, measured at aft case opening.
TSRBF	0.0	Thickness (in) of stress relief boot in forward closure Type 1, measured at RIGN radius.
W	0.0	Minimum distance (in) between adjacent star tips
WFLIM	1.0	Maximum allowed web fraction (TAUW1/RFA1)
FDMTR	T	Search control for motor outside diameter (DMOTOR). See Note 3.
FLFWD	T	Search control for length of forward portion of grain (LFWD). See Note 3.
FLTAPR	T	Search control for length of tapered portion of grain (LTAPER). See Note 3.
FTCASE	T	Search control for case wall thickness in cylindrical section (TCASE). See Note 3.
FTYP1	T	Search control for all dimensions describing grain cross-section (R5A1, TAUW1, ALPHA1, LSA1, LSA14). See Note 3.

NOTES

1. Input required for all problems.
2. Input required for all problems with forward closure Type 1.
3. Logical command to specify parameters that may be adjusted during optimization search. T = parameter will be maintained constant at input value; F = parameter will not be maintained at input value, but will be adjusted.

FORWARD CLOSURE TYPE 1



(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter

Figure 5. Input Nomenclature for Forward Closure Type 1

1st Possibility

RFA1<B5F

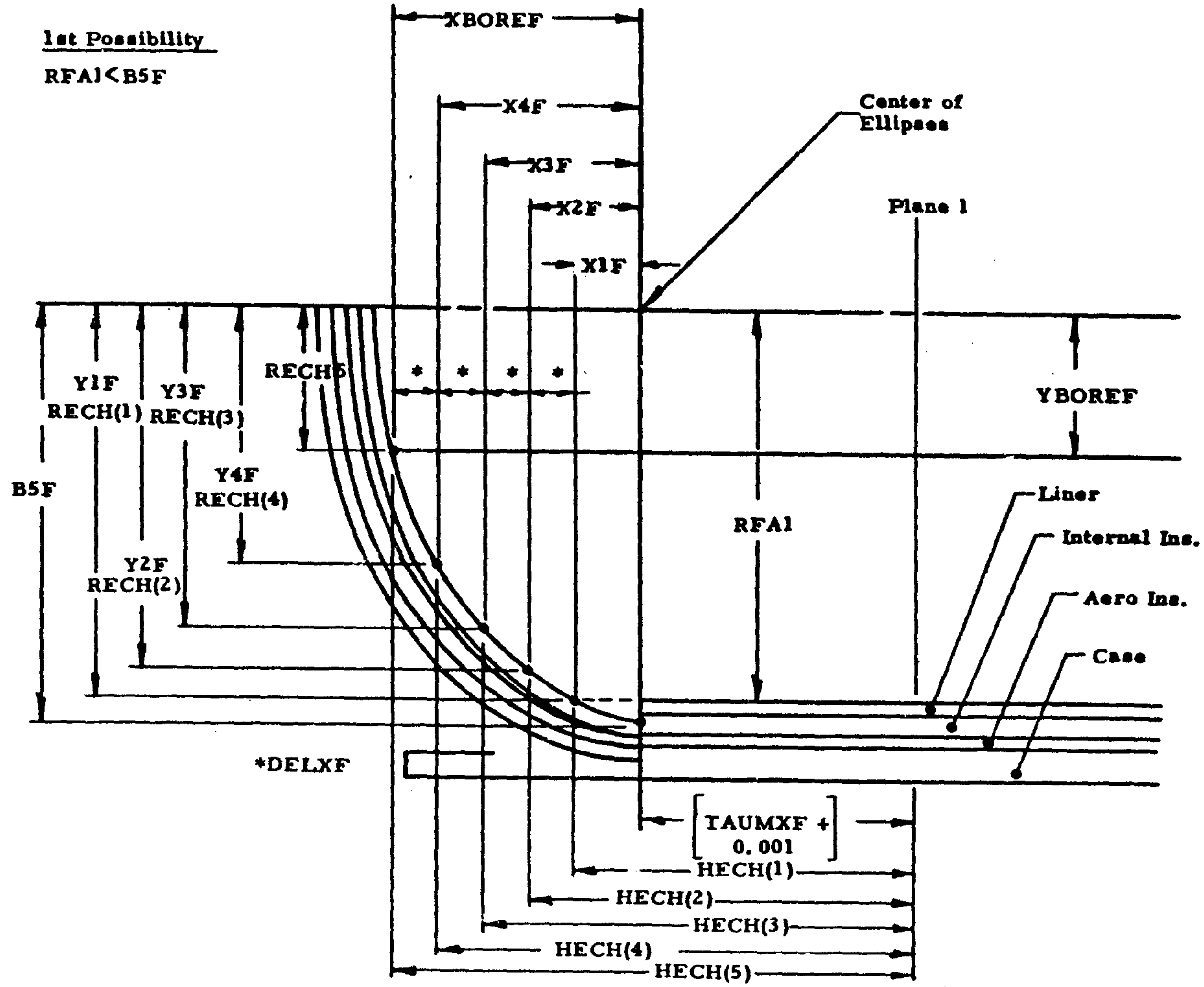


Figure 6. Internal and Output Nomenclature for Forward Closure Type 1 (RFA1< B5F)

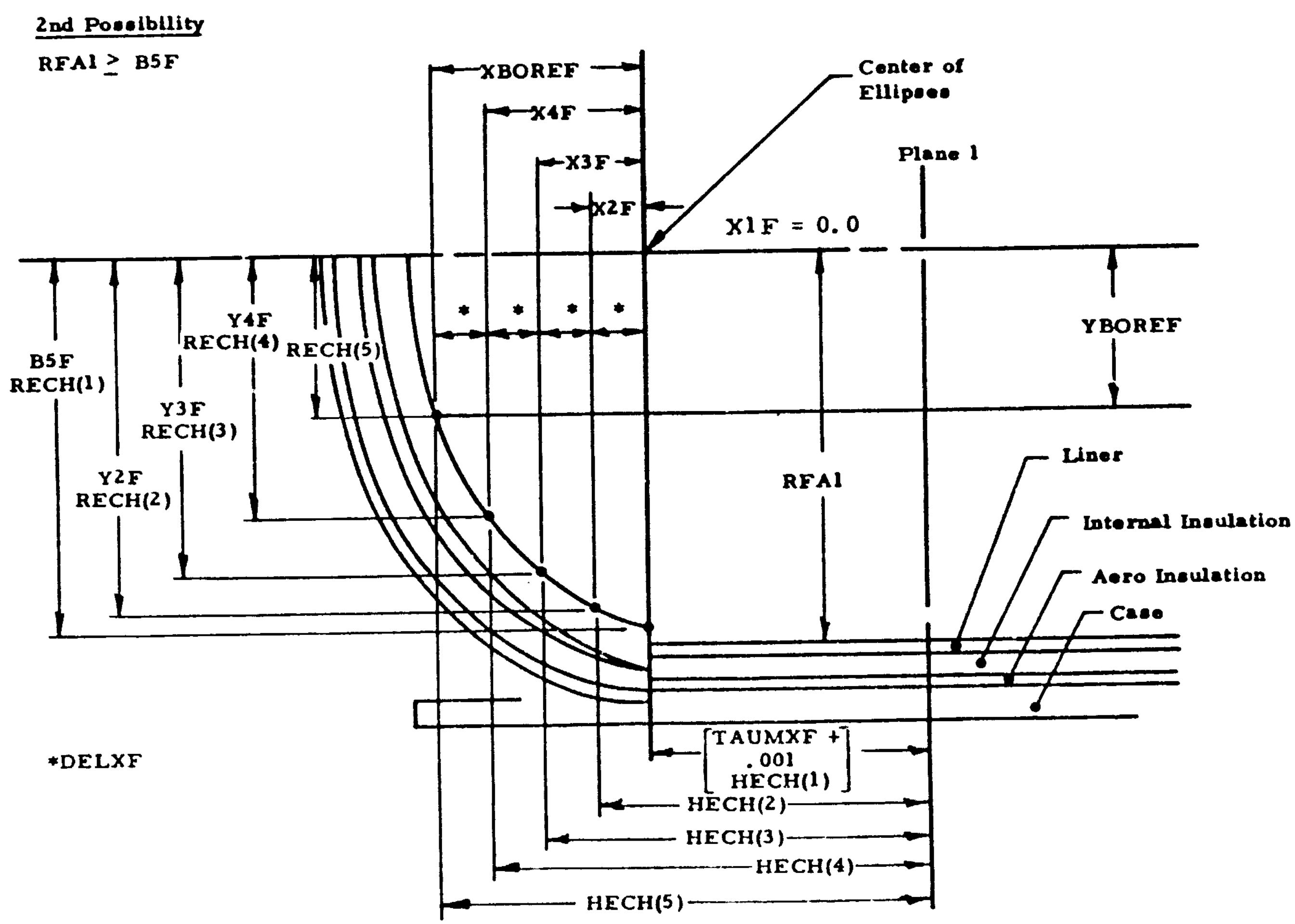
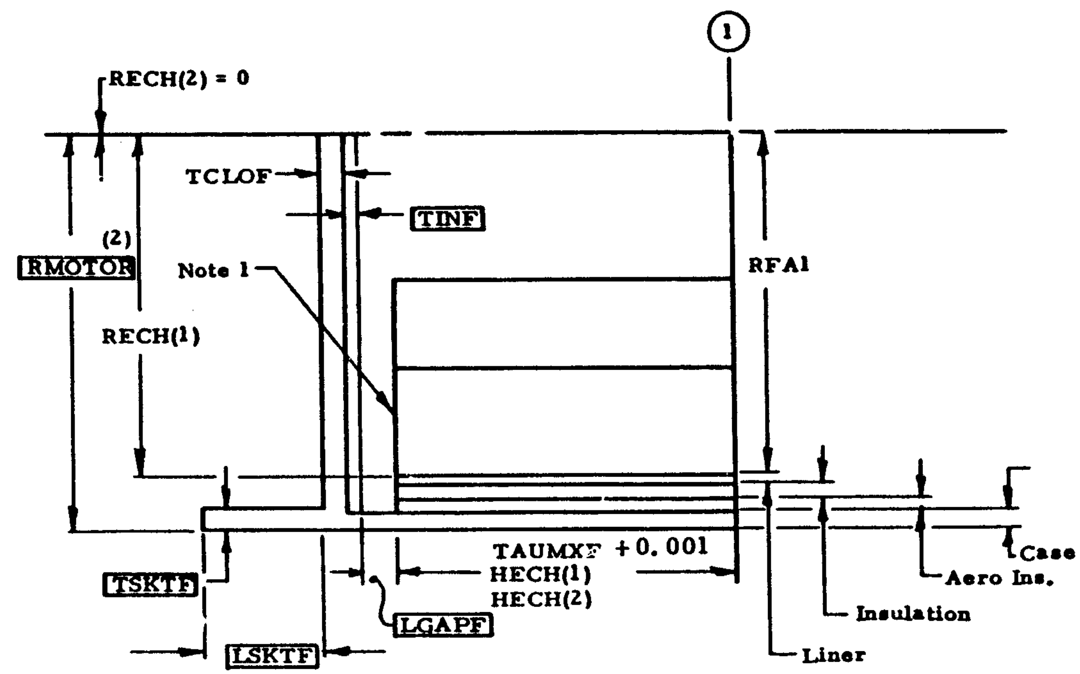


Figure 7. Internal and Output Nomenclature for Forward Closure Type 1 ($RFA1 \geq B5F$)

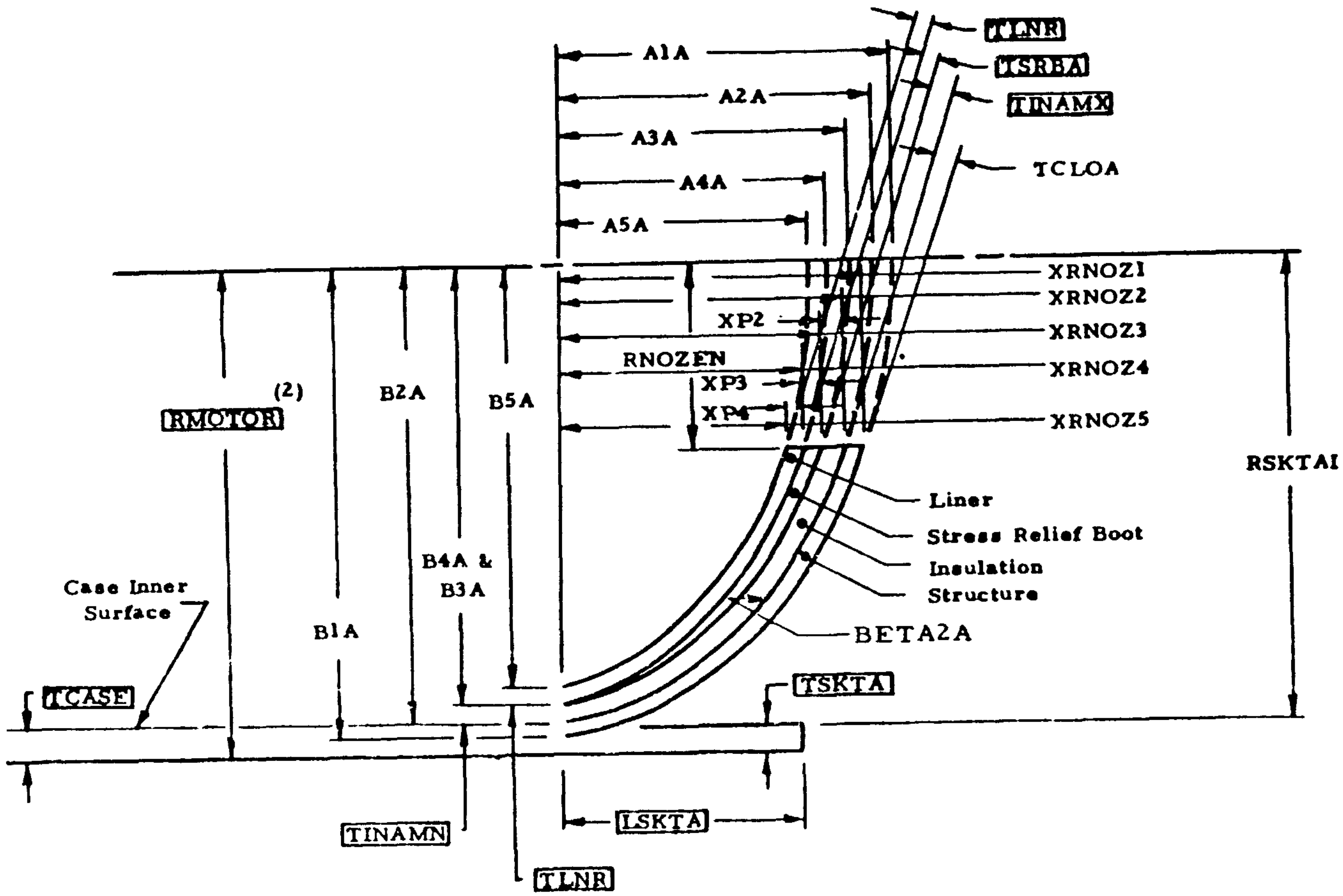
HEADEND TYPES 2 AND 3



(1) This face inhibited if FWDINH = T, not inhibited if FWDINH = F
(2) Input as appropriate diameter
(3) Dimensions shown in blocks are input; others are output

Figure 8. Input Nomenclature for Forward Closure Type 2 and Type 3

AFT CLOSURE TYPE 1



(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter

Figure 9. Input Nomenclature for Aft Closure Type 1

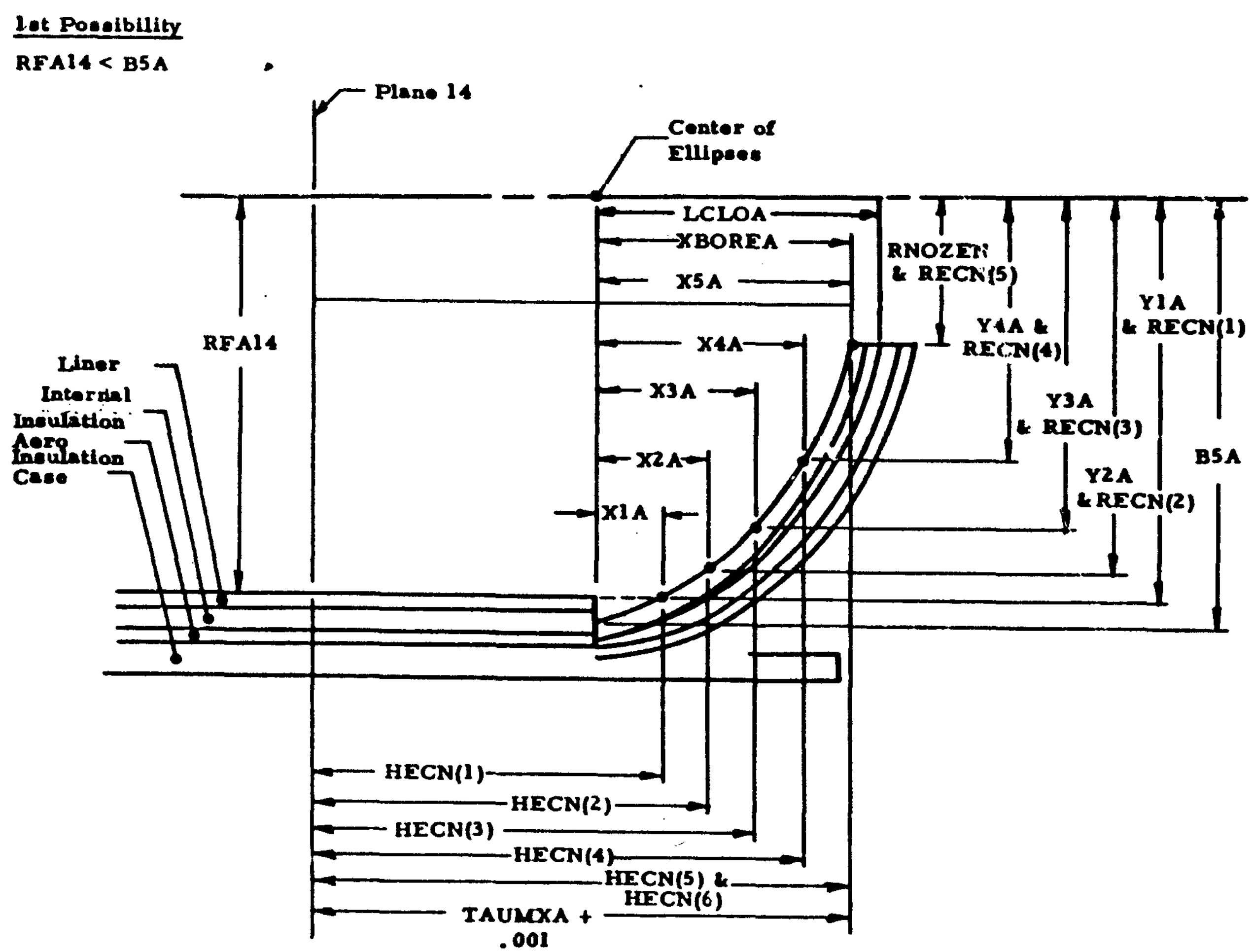


Figure 10. Internal and Output Nomenclature for Aft Closure Ty.e 1 (RFA14 < B5A)

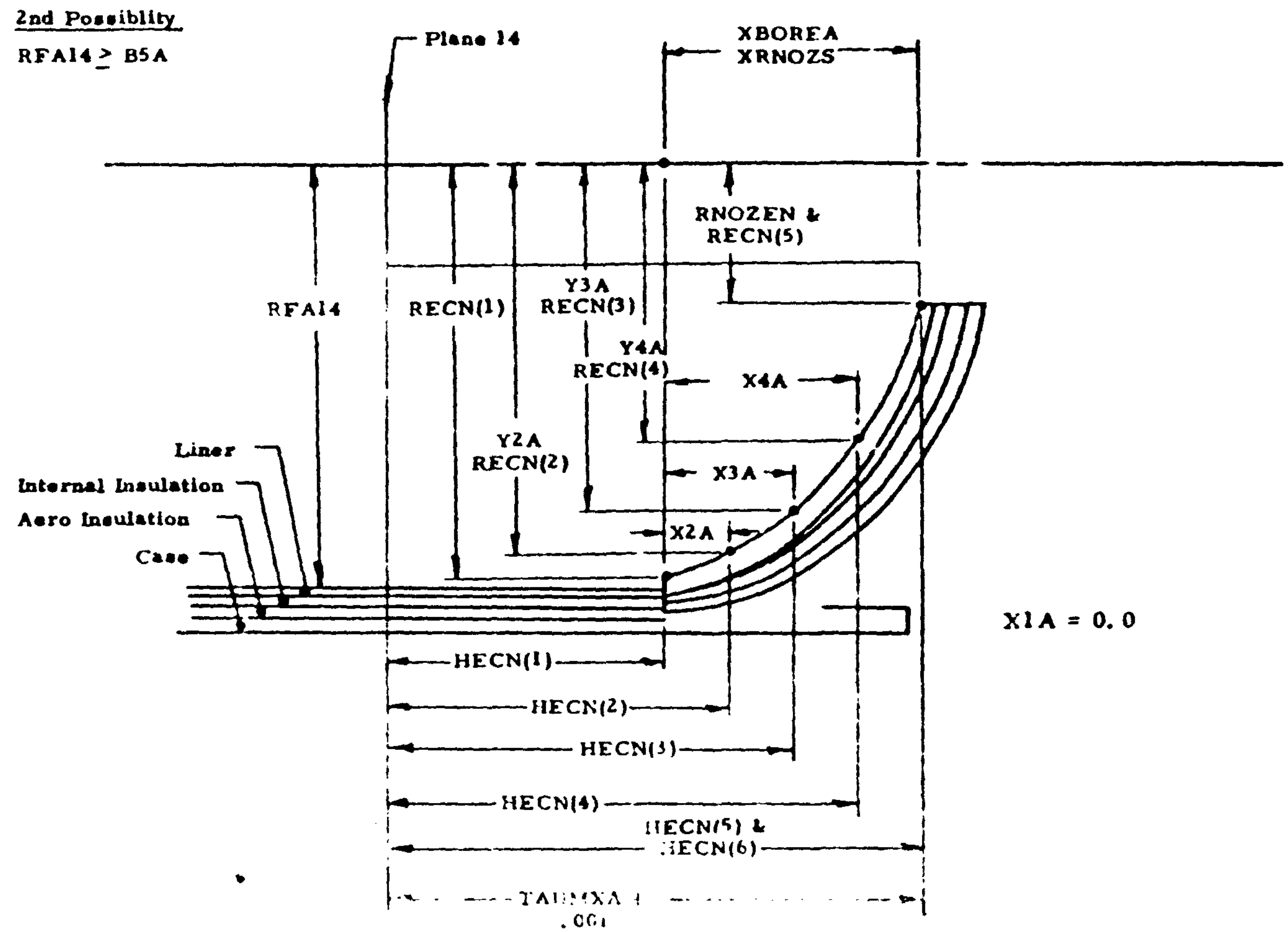
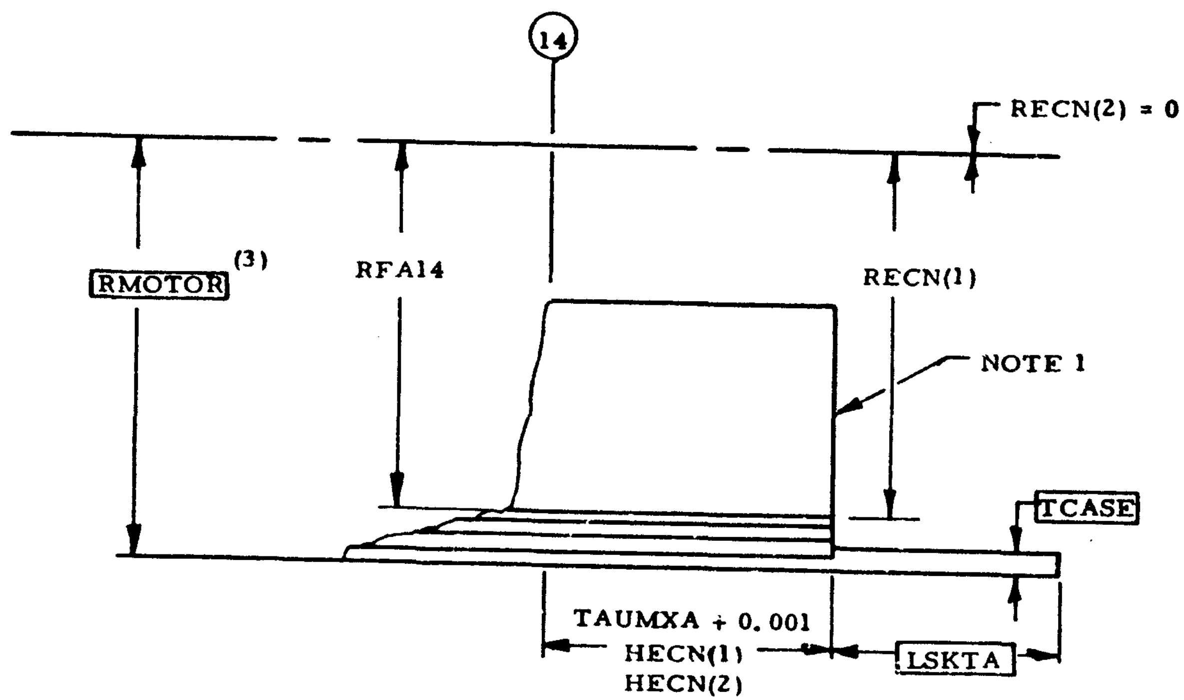


Figure 11. Internal and Output Nomenclature For Aft Closure Type 1 (RFA14 ≥ B5A)

AFT CLOSURE TYPE 2



(1) This face inhibited if AFTINH = T, not inhibited if AFTINH = F
(2) Dimensions shown in blocks are input; others are output
(3) Input as appropriate diameter

Figure 12. Input Nomenclature for Aft Closure Type 2

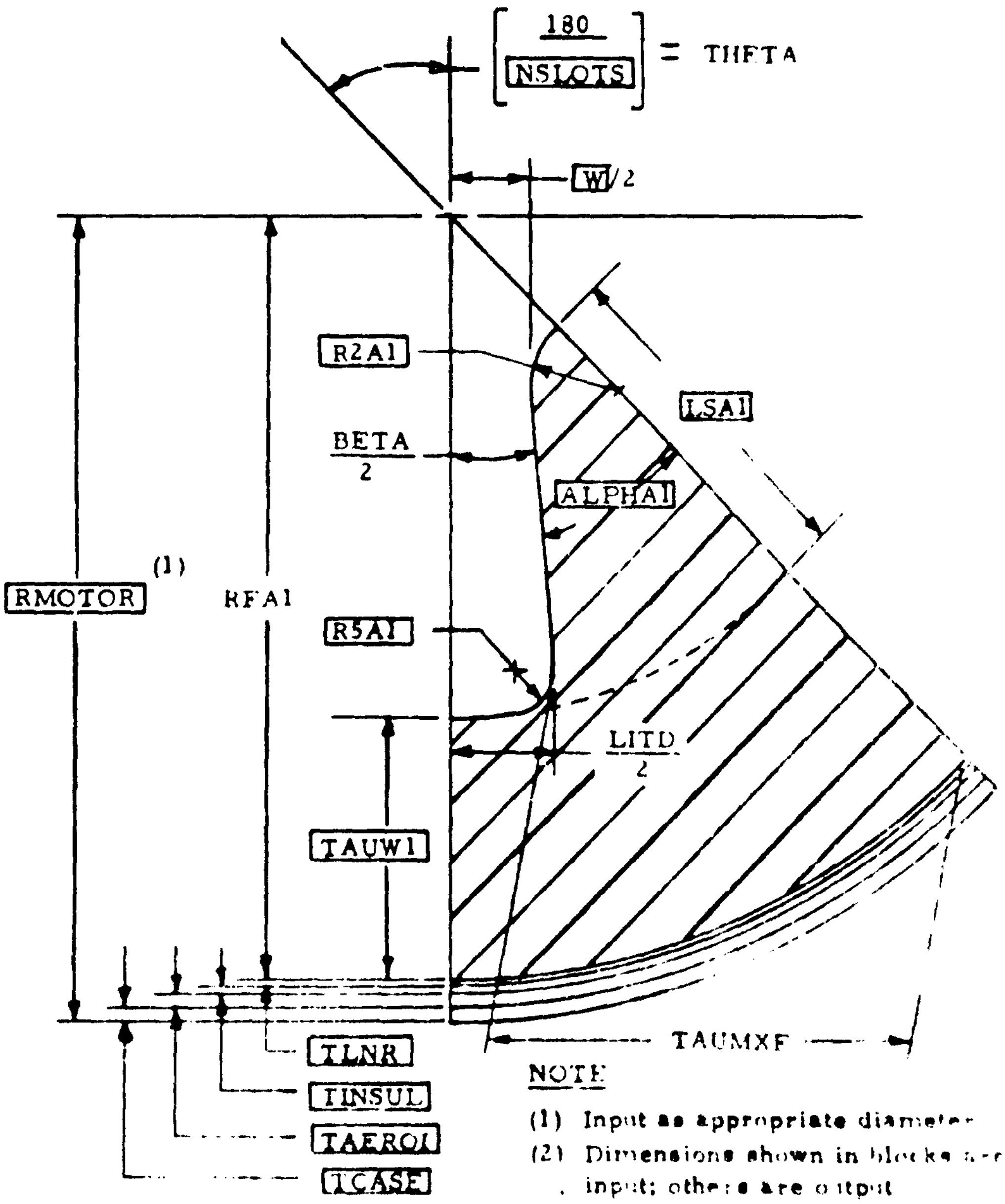
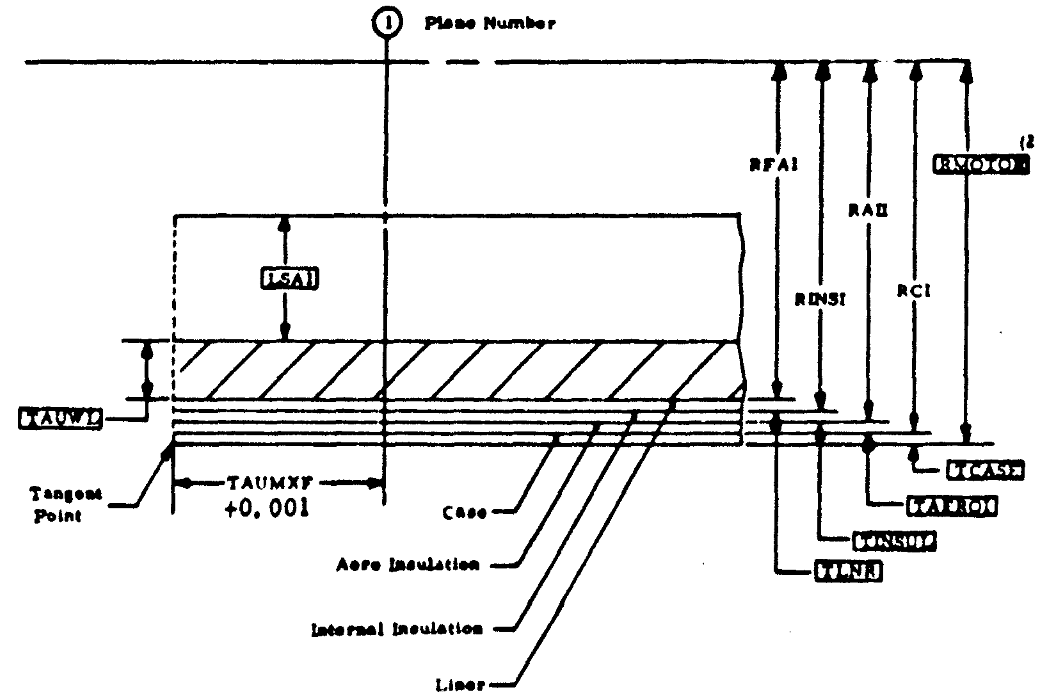


Figure 13. Input Nomenclature for Type 1 Grain (Star)

IFWDCL = 1

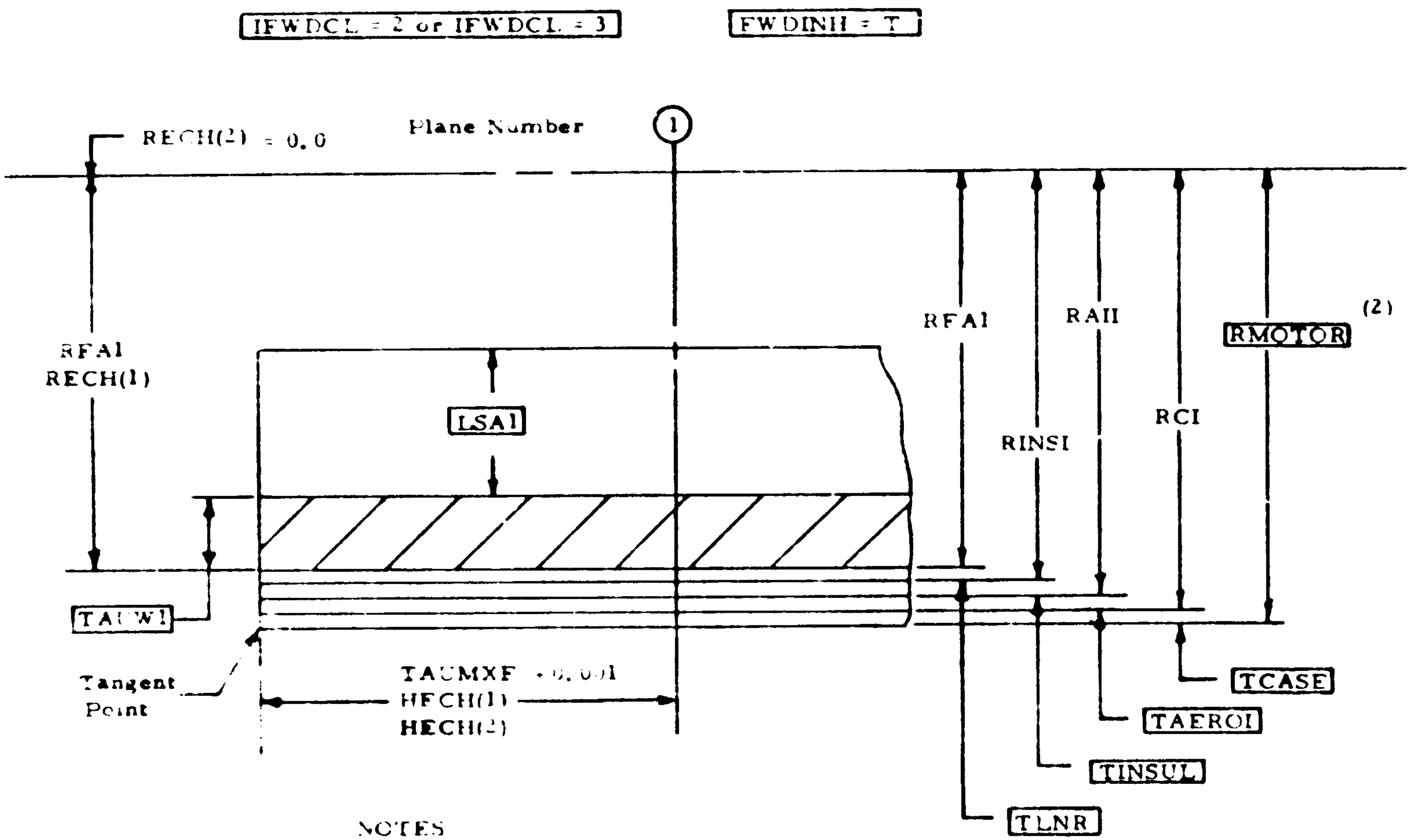


NOTES

(1) Dimensions shown in blocks are input; others are output

(2) Input as appropriate diameter

Figure 14. Nomenclature for Head-end of Grain Type 1, Forward Closure Type 1

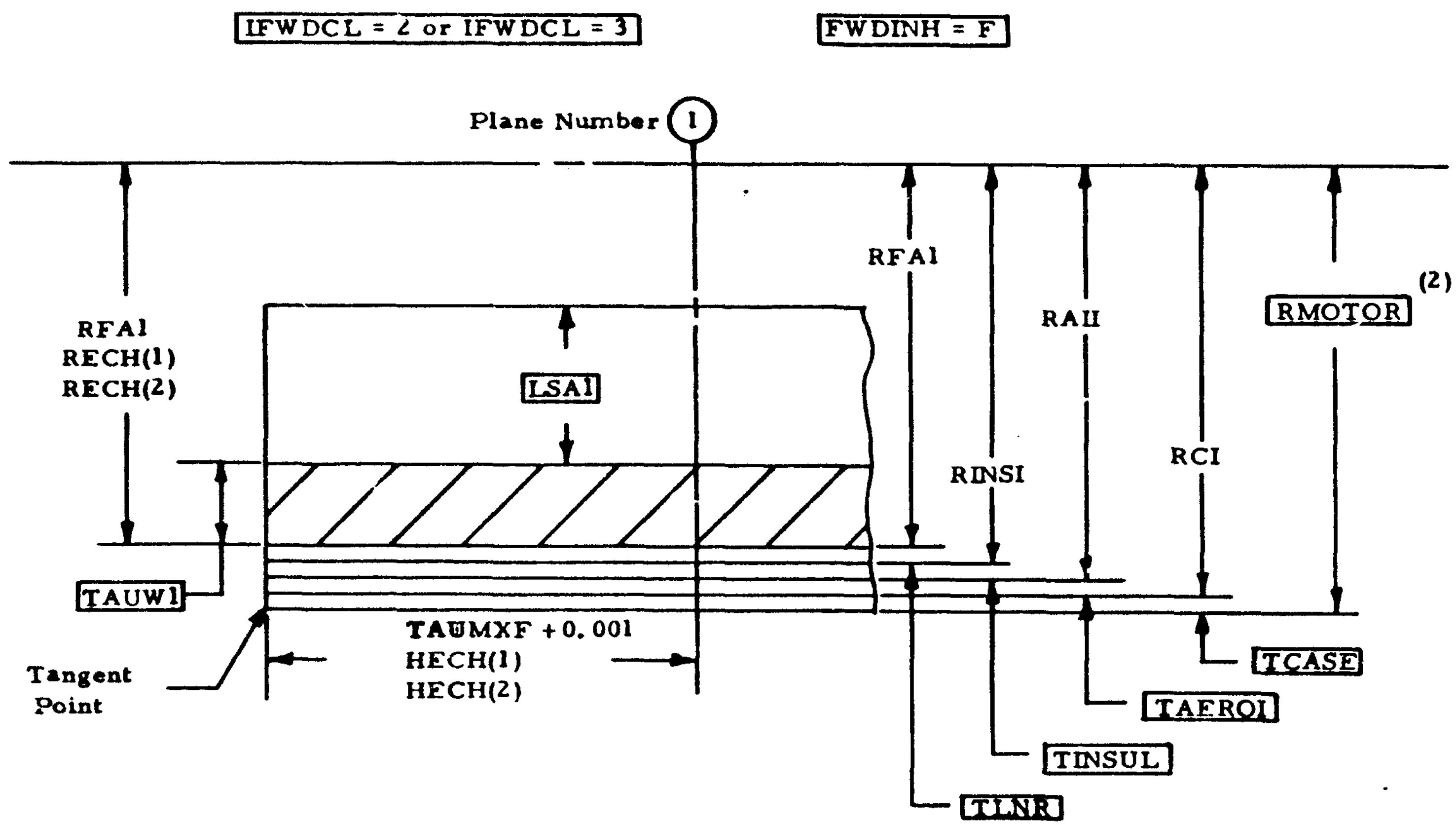


NOTES

Dimensions shown in blocks are input; others are output

Input as appropriate diameter

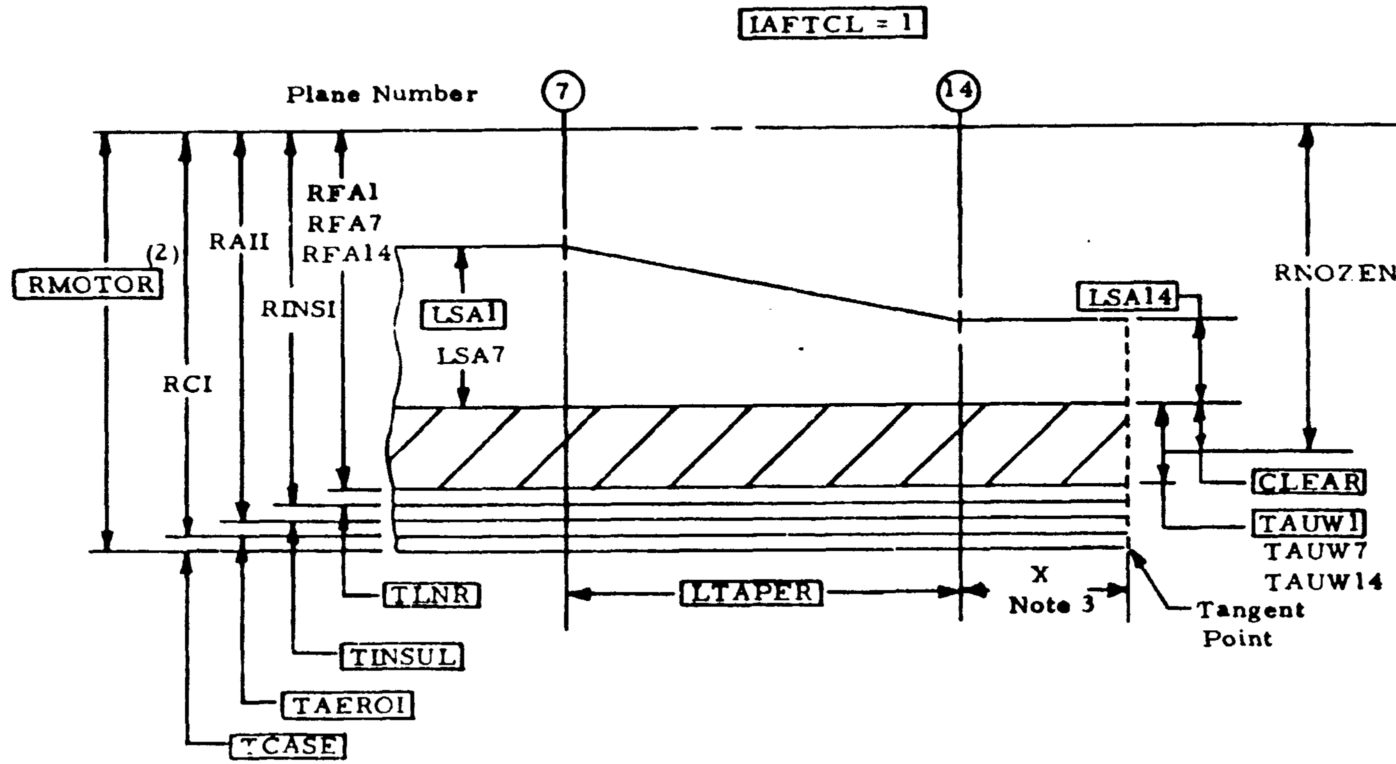
Figure 15. Nomenclature for Head-end of Grain Type 1, Forward Closure Type 2 or Type 3 (Contoured)



NOTES

(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter

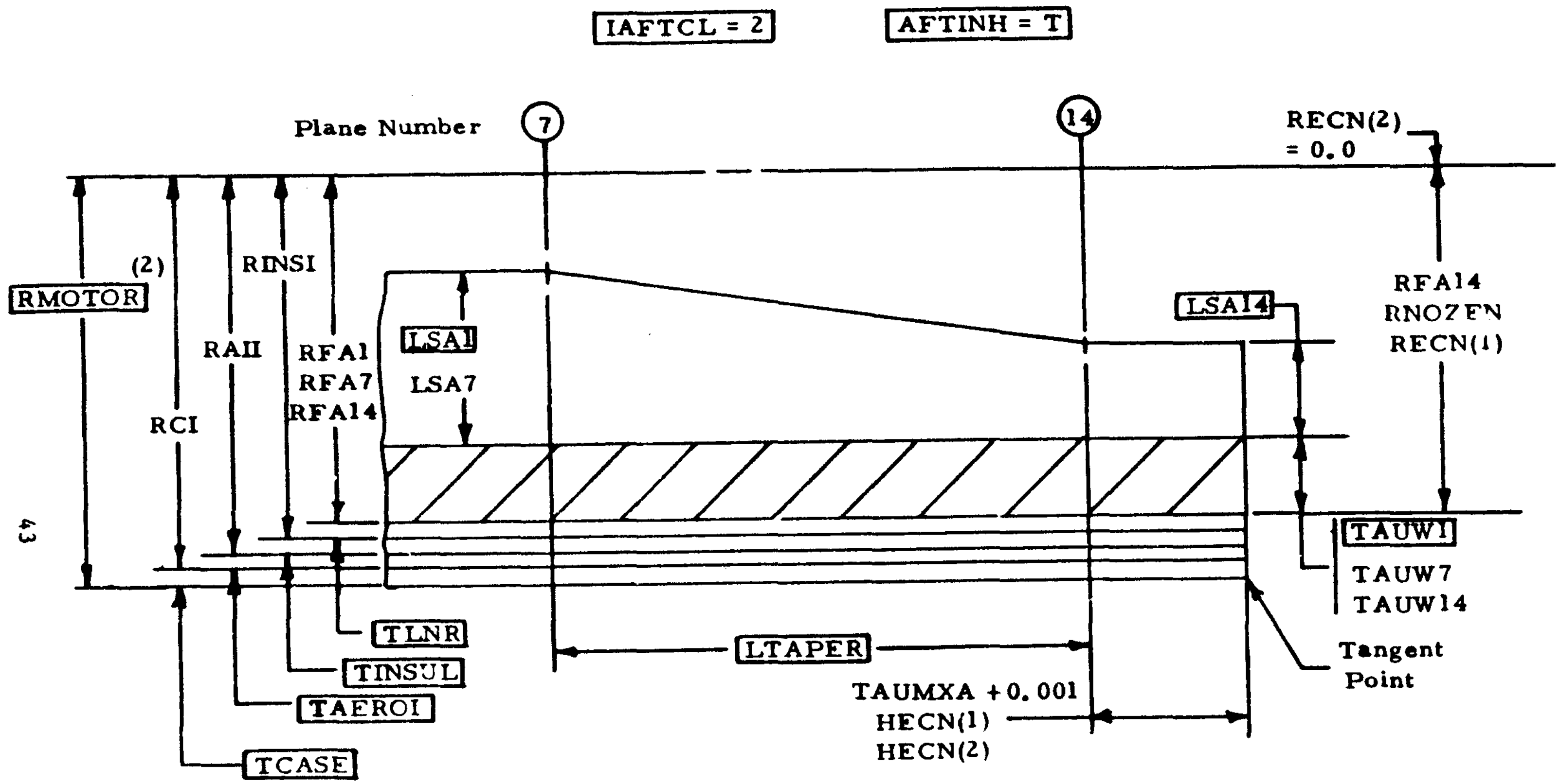
Figure 16. Nomenclature for Head-end of Grain Type 1, Forward Closure Type 2 or Type 3 (Not Inhibited)



NOTES

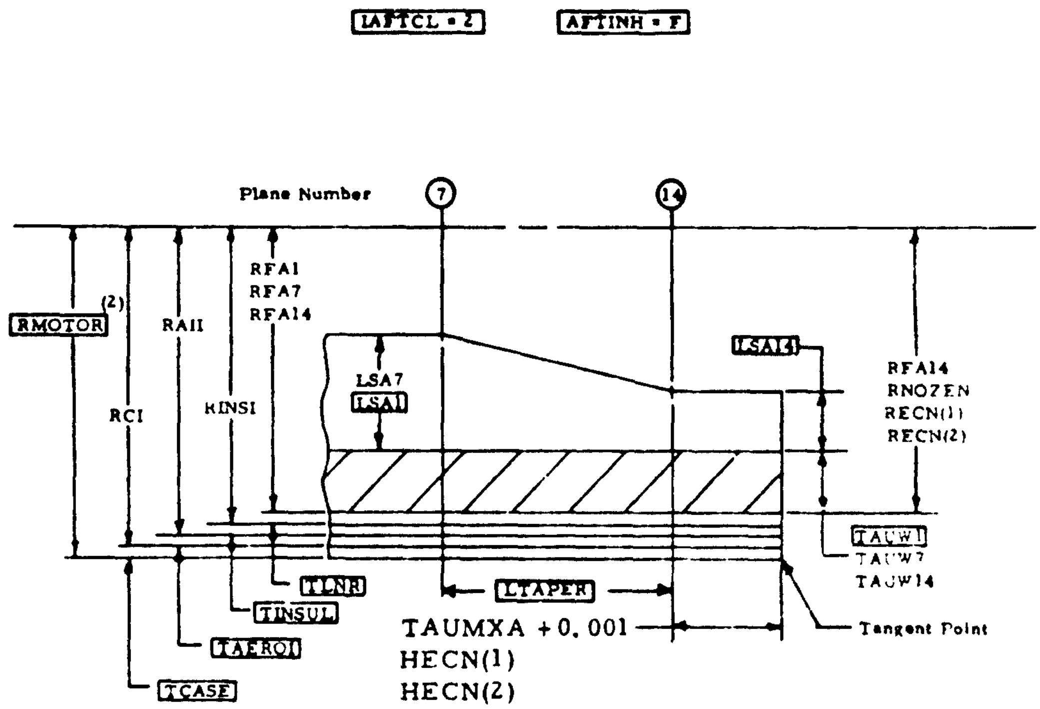
(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter
(3) X=(HECN(1)-X1A) if RFA14<B5A; X=HECN(1) if RFA14≥B5A

Figure 17. Nomenclature for Aft End of Grain Type 1, Aft Closure Type 1



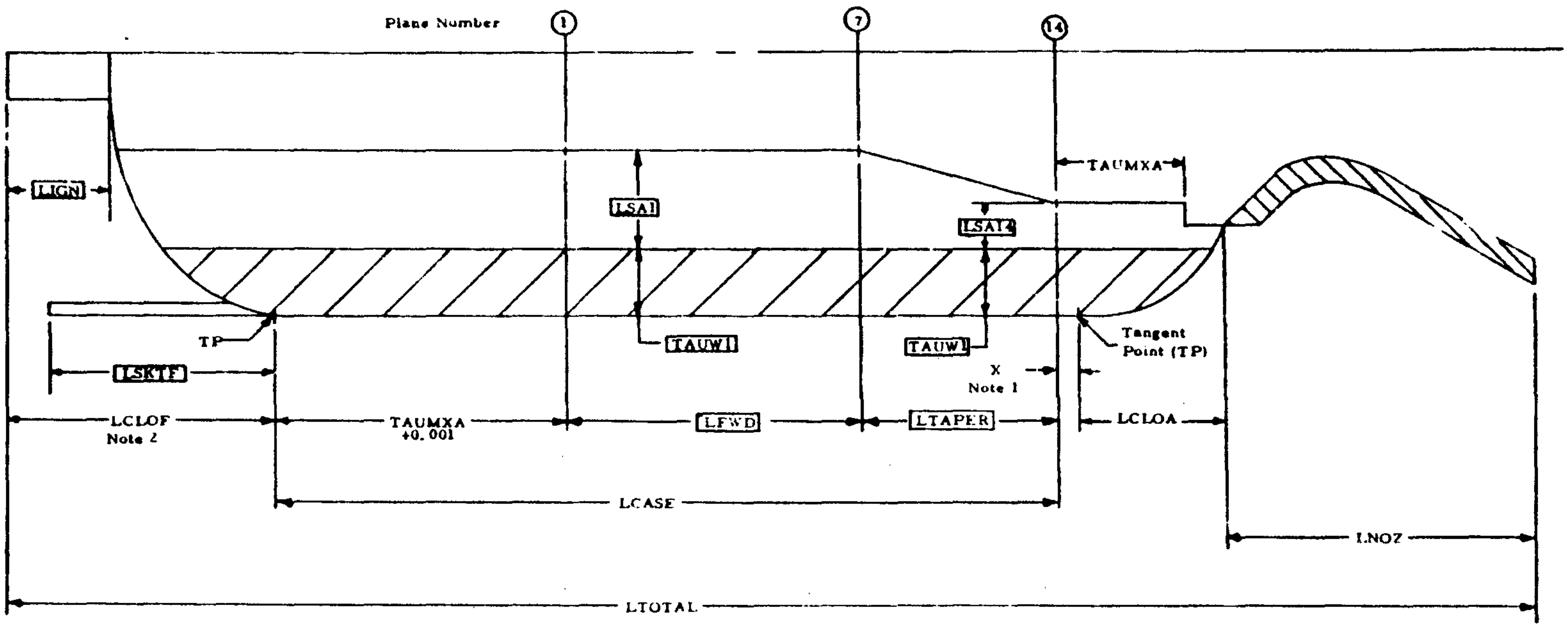
(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter

Figure 18. Nomenclature for Aft End of Grain Type 1, Aft Closure Type 2 (Inhibited)



(1) Dimensions shown in blocks are input: others are output
(2) Input as appropriate diameter

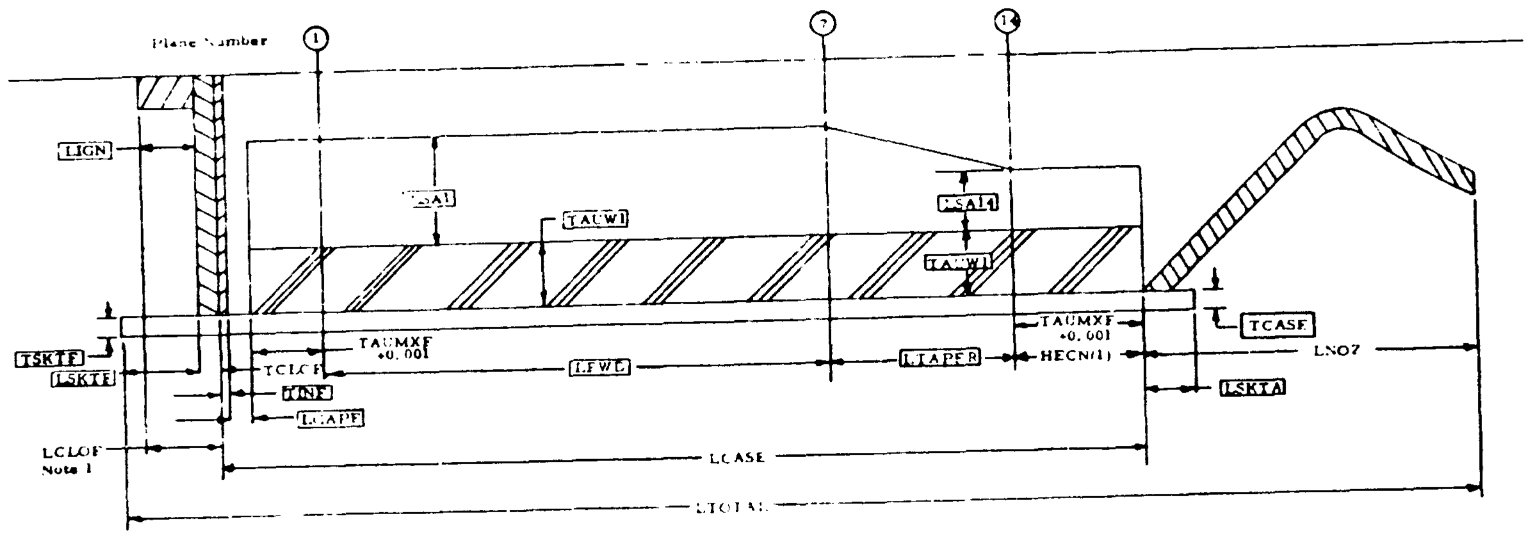
Figure 19. Nomenclature for Aft End of Grain Type 1, Aft Closure Type 2 (Not Inhibited)



NOTES

(1) For Aft Closure Type 1, X = (HECN(1) - X1A) if RFA14 < B5A, or is X = HECN(1) if RFA14 ≥ B5A
(2) LSKTF used to calculate LTOTAL if LSKTF > LCLOF
(3) Dimensions shown in blocks are input; others are output

Figure 20. Nomenclature for Grain Type 1 with Aft Closure Type 1 and Forward Closure Type 1



NOTES:

(1) LCLOF used to calculate LTOTAL if LCLOF > LSKTF

(2) Dimensions shown in blocks are input; others are output

Figure 21. Nomenclature for Grain Type 1 with Aft Closure Type 2 and Forward Closure Type 2 or Type 3

TABLE 5

OUTPUT OF GRAIN DIMENSION SETUP

GRAIN TYPE 1 - STAR

Parameter Name	Definition and Units
ALPHA1 (1)-(14)	Included half-angle (deg) of star tip at input planes.
BETA	Included angle (deg) of propellant valley.
B5A	See Figure 10.
B5F	See Figure 6.
HECH(I)	Length (in) measured forward from Plane 1 to describe outside propellant surface in forward closure (I = 1,....5).
HECN(I)	Length (in) measured aft from Plane 14 to describe outside propellant surface in aft closure (I = 1,....5).
LCASE	Length (in) of cylindrical portion of case
LCLOA	Length (in) of aft elliptical closures from case-closure tangent point to aft most edge of stress-relief boot at RNOZEN.
LCLOF	Length (in) of forward closure from case-closure tangent point to forward face of igniter.
LFWD	Length (in) of forward untapered portion of grain.
LITD	Distance (in) across propellant valley for use in propellant structural analysis.
LSA1-LSA14	Height (in) of star tip at input planes, measured from web.
LSMAX	Maximum possible star tip height (in) for particular set of grain cross-section dimensions.
LTAPER	Length (in) of aft tapered portion of grain.
L7T1-L14T1	Length (in) from Plane 1 to downstream input planes (e.g., from Plane 7 to Plane 1, etc.).
OBCLR	Penalty for CLEAR greater than current TAUW1.
OBJALF	Penalty for ALPHA1 $<$ 0, or ALPHA1 $>$ (180/NSLOTS), or ALPHA1 $>$ ALPHMX.

Table 5

OUTPUT OF GRAIN DIMENSION SETUP - GRAIN TYPE 1 (contd.)

Parameter Name	Definition and Units
OBJLS	Penalty for LSA1 greater than LSMAX or less than LSMIN (LSMIN = R2A1).
OBJR5	Penalty for fillet radius R5 less than R5MIN or larger than R5MAX.
OBJTAU	Penalty for web thickness greater than input limit (WFLIM x RFA1) or less than zero.
OBLFWD	Penalty for LFWD less than zero.
OBLS14	Penalty for LSA14 greater than LSA1 or less than LSMIN (LSMIN = R2A1).
OBLTPR	Penalty for LTAPER less than zero.
OBTCMN	Penalty for TCASE less than TFABC.
RAII	Inside radius (in) of aerodynamic heating insulation.
RCI	Inside radius (in) of case cylindrical section.
RECH(I)	Radii (in) describing outside propellant surface in forward closure (I = 1,... 5).
RECN(I)	Radii (in) describing outside propellant surface in aft closure (I = 1,... 5).
RFA1-RFA14	Fuel radius (in) at input planes.
RINSI	Inside radius (in) of case insulation.
RNOZEN	Radius (in) at aft end of case which is made compatible with the nozzle entrance radius (RIJ1).
R2A1-R2A14	Star tip radius (in) at input planes.
R5A1-R5A14	Fillet radius (in) between star tip and web at input planes.
R5MAX	Maximum possible fillet radius (in) R5 for particular set of grain cross-section dimensions.
R5MIN	Minimum possible fillet radius (in) R5 for particular set of grain cross-section dimensions.
TAUW1-TAUW14	Web thickness (in) at input planes.
TAUMXA	Maximum distance burned (in) at Plane 14.
TAUMXF	Maximum distance burned (in) at Plane 1.

Table 5

OUTPUT OF GRAIN DIMENSION SETUP - GRAIN TYPE 1 (contd.)

Parameter Name	Definition and Units
THETA	Angle (deg) formed by grain cross-section symmetry (180/NSLOTS).
W	Minimum separation distance (in) between adjacent star tips.
WAEROI	Weight (lb) of aerodynamic heating insulation.
WCASCY	Weight (lb) of cylindrical portion of case.
WEBFR	Web fraction at Plane 1.
WINA	Weight (lb) of insulation in aft closure.
WINF	Weight (lb) of insulation in forward closure.
WINSUL	Weight (lb) of all insulation in pressure vessel.
WINSCY	Weight (lb) of insulation in cylindrical portion of case.
WLNRA	Weight (lb) of liner in aft closure.
WLNRCY	Weight (lb) of liner in cylindrical portion of case.
WLNRF	Weight (lb) of liner in forward closure.
WSKTA	Weight (lb) of aft thrust skirt.
WSKTF	Weight (lb) of forward thrust skirt.
WSRBA	Weight (lb) of stress relief boot in aft closure.
WSRBF	Weight (lb) of stress relief boot in forward closure.
X	See Figure 20.
X1A	See Figure 10.

NOTES

1. See Volume I for further illustrations of grain Type 1 dimensions.

GRAIN TYPE 2 - WAGON WHEEL

This block of input data describes the wagon wheel grain configuration and the forward and aft closures. All data are contained in a single namelist GRAIN2.

The closure inputs are included in the input block for each grain type. However, the illustrations of the closures that show common parameters are included only in the grain Type 1 description.

Input data are provided to a subroutine SETUP2 that (1) confirms the geometric validity of all the grain dimensions (e.g., PATSH-adjusted lengths greater than zero, initial grain dimensions "close" properly, etc.); (2) checks dimensions against user-supplied limits (e.g., propellant web fraction less than limit, clearances between propellant and case greater than limit, etc.); (3) generates dimensions that describe propellant initial internal and external surfaces to the ballistic simulation module; (4) calculates all inert weights in the pressure vessel (except for pressure vessel closures, which is done after a design pressure is available from the ballistic simulation). The results of these analyses are given as part of this block of code output.

Dimensions describing the grain cross-section (TAUW1, R5A1, LSA1 LSA14) can be held constant during an optimization by setting FTYP2 = T, or they can be adjusted by PATSH by setting FTYP2 = F. There is no provision for Grain Type 2 to selectively fix some and vary others of these dimensions.

TABLE 6

NAMELIST/GRAIN2

INPUTS FOR TYPE 2 GRAIN BALLISTIC SIMULATION

Parameter Name	Default Value	Definition and Units
BETA2A	0.0 Note 2	Ellipse ratio (major/minor diameter) of inside surface of pressure vessel aft closure Type 1.
BETA2F	0.0 Note 2	Ellipse ratio (major/minor diameter) of inside surface of pressure vessel forward closure Type 1.
CLEAR	0.0	Radial clearance (in) between port radius and radius of aft closure opening on aft closure Type 1. Positive when port is smaller than opening.
DELAI	0.0	Density (lbm/cu in) of insulation to protect grain against aerodynamic heating.
DELCAS	0.0	Density (lbm/cu in) of pressure vessel (case cylindrical section and integral closures).
DELCLO	0.0	Density (lbm/cu in) of Type 2 forward closure.
DELINS	0.0	Density (lbm/cu in) of case internal insulation.
DELLNR	0.0	Density (lbm/cu in) of liner.
DELSRB	0.0	Density (lbm/cu in) of stress relief boot.
DMOTOR	Note 1	Outside diameter (in) of motor.
LFWD	Note 1	Length (in) of forward untapered portion of grain.
LTAPER	Note 1	Length (in) of aft tapered portion of grain.
LGAPF	0.0	Length (in) between forward face of grain and aft face of insulation on Forward Closure Types 2 or 3.
LIGN	0.0	Length (in) of igniter and/or safe-and-arm device that extends forward of the outside surface of the forward closure.
LSA1	Note 1	Height (in) of star tip at Plane 1, measured from web.
LSA14	Note 1	Height (in) of star tip at Plane 14, measured from web.

Table 6

INPUTS FOR TYPE 2 GRAIN BALLISTIC SIMULATION (contd.)

Parameter Name	Default Value	Definition and Units
LSKTA	0.0	Length (in) of aft thrust skirt.
LSKTF	0.0	Length (in) of forward thrust skirt.
NSLOTS	Note 1	Integer to specify number of longitudinal slots in grain. Must be ≥3 for Type 2 grain.
R2A1	0.0	Radius (in) on tip of star point.
R5A1	0.0	Fillet radius (in) R5 at Plane 1 between star tip and web.
TAEROI	0.0	Thickness (in) of insulation to protect grain against aerodynamic heating.
TAUW1	Note 1	Web thickness (in) at Plane 1.
TCASE	Note 1	Thickness (in) of pressure vessel cylindrical section.
TFABC	0.0	Minimum allowed thickness (in) of case cylindrical section due to fabrication considerations.
TINAMN	0.0	Thickness (in) of insulation in aft closure Type 1, measured at tangent point of closure and case cylindrical section.
TINAMX	0.0	Thickness (in) of insulation in aft closure Type 1, measured at opening of closure (where nozzle attaches).
TINF	0.0	Thickness (in) of insulation of flat plate forward closures (Type 2 or Type 3).
TINFMN	0.0	Thickness (in) of insulation in forward closure Type 1, measured at tangent point of closure and case cylindrical section.
TINFMX	0.0	Thickness (in) of insulation in forward closure Type 1, measured at RIGN radius.
TINSUL	0.0	Thickness (in) of insulation. Constant over entire interior surface of cylindrical section.
TLNR	0.0	Thickness (in) of liner, constant over entire interior surface.
TSKTA	0.0	Thickness (in) of aft thrust skirt.
TSKTF	0.0	Thickness (in) of forward thrust skirt.

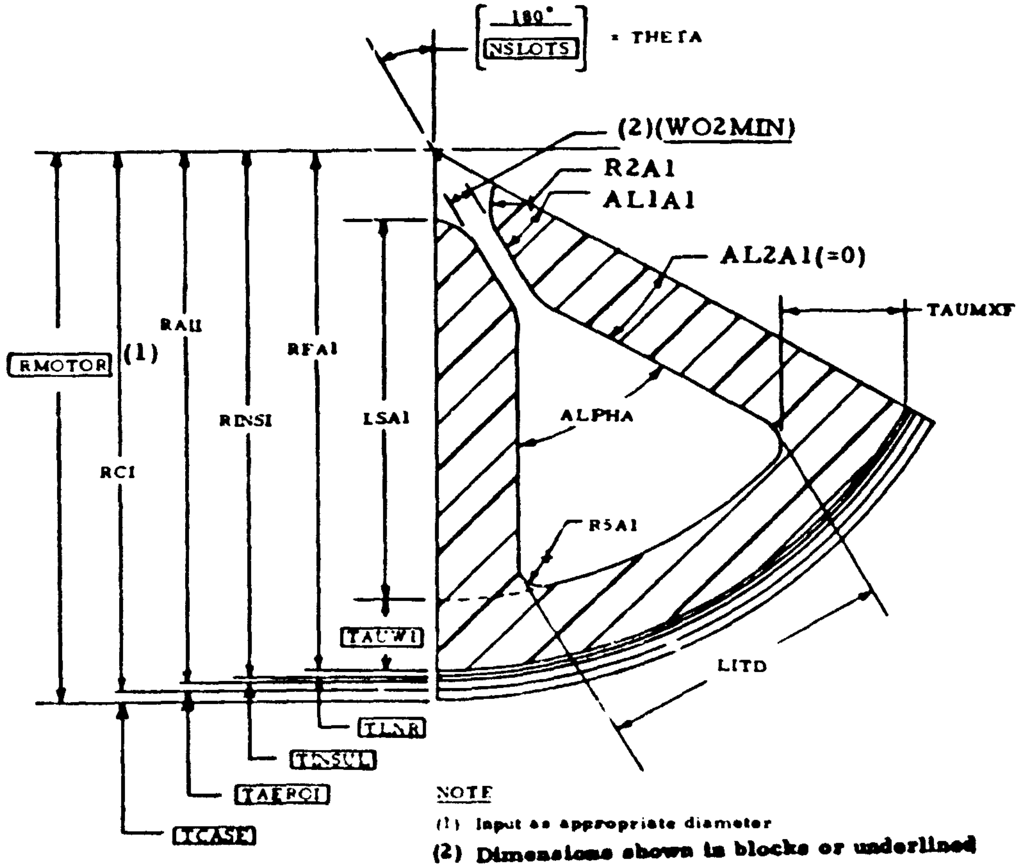
Table 6

INPUTS FOR TYPE 2 GRAIN BALLISTIC SIMULATION (contd.)

Parameter Name	Default Value	Definition and Units
TSRBA	0.0	Thickness (in) of stress relief boot in aft closure Type 1, measured at aft case opening.
TSRBF	0.0	Thickness (in) of stress relief boot in forward closure Type 1, measured at RIGN radius.
WO2MIN	0.0	Half the minimum distance (in) between adjacent star tips.
WFLIM	1.0	Maximum allowed web fraction (TAUW1/RFA1).
FDMTR	T	Search control for motor outside diameter (DMOTOR). See Note 3.
FLFWD	T	Search control for length of forward portion of grain (LFWD). See Note 3.
FLTAPR	T	Search control for length of tapered portion of grain (LTAPER). See Note 3.
FTCASE	T	Search control for case wall thickness in cylindrical section (TCASE). See Note 3.
FTYP2	T	Search control for all dimensions describing grain cross-section (R5A1, R2A1, TAUW1, LSA1, LSA14). See Note 3.

NOTES

1. Input required for all problems.
2. Input required for all problems with forward closure Type 1.
3. Logical command to specify parameters that may be adjusted during optimization search. T = parameter will be maintained constant at input value; F = parameter will not be maintained at input value, but will be adjusted.



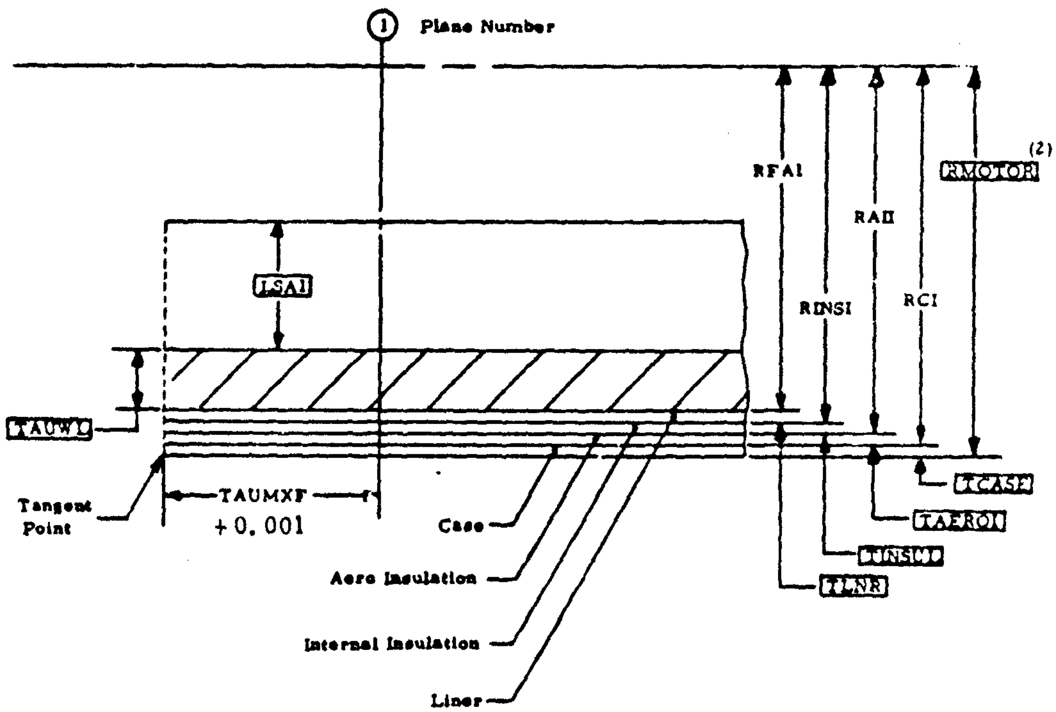
NOTE

(1) Input as appropriate diameter

(2) **Dimensions shown in blocks or underlined are input; all others are output**

Figure 22. Input Nomenclature for Type 2 Grain (Wagon Wheel)

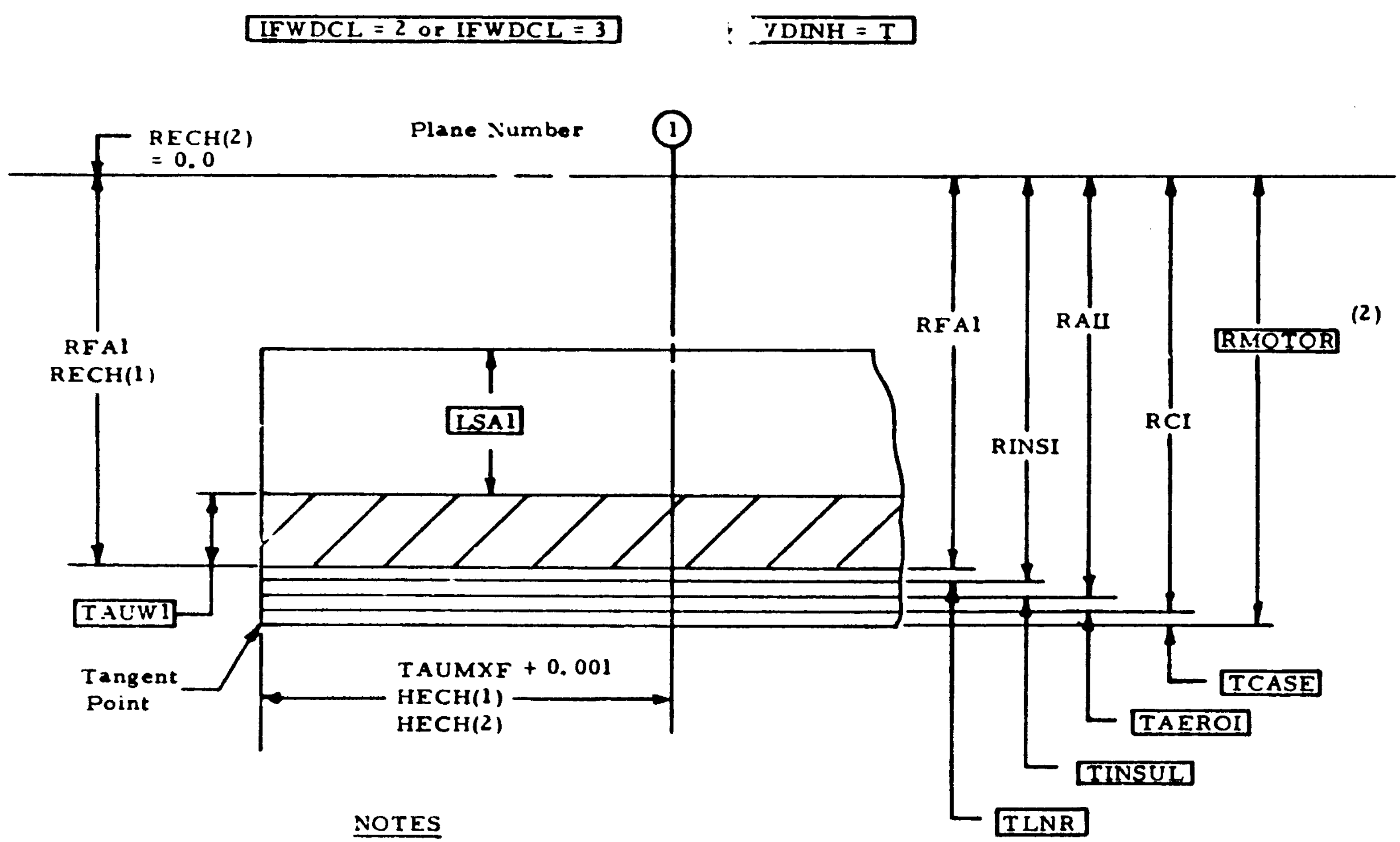
IFWDCL = 1



NOTES

(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter

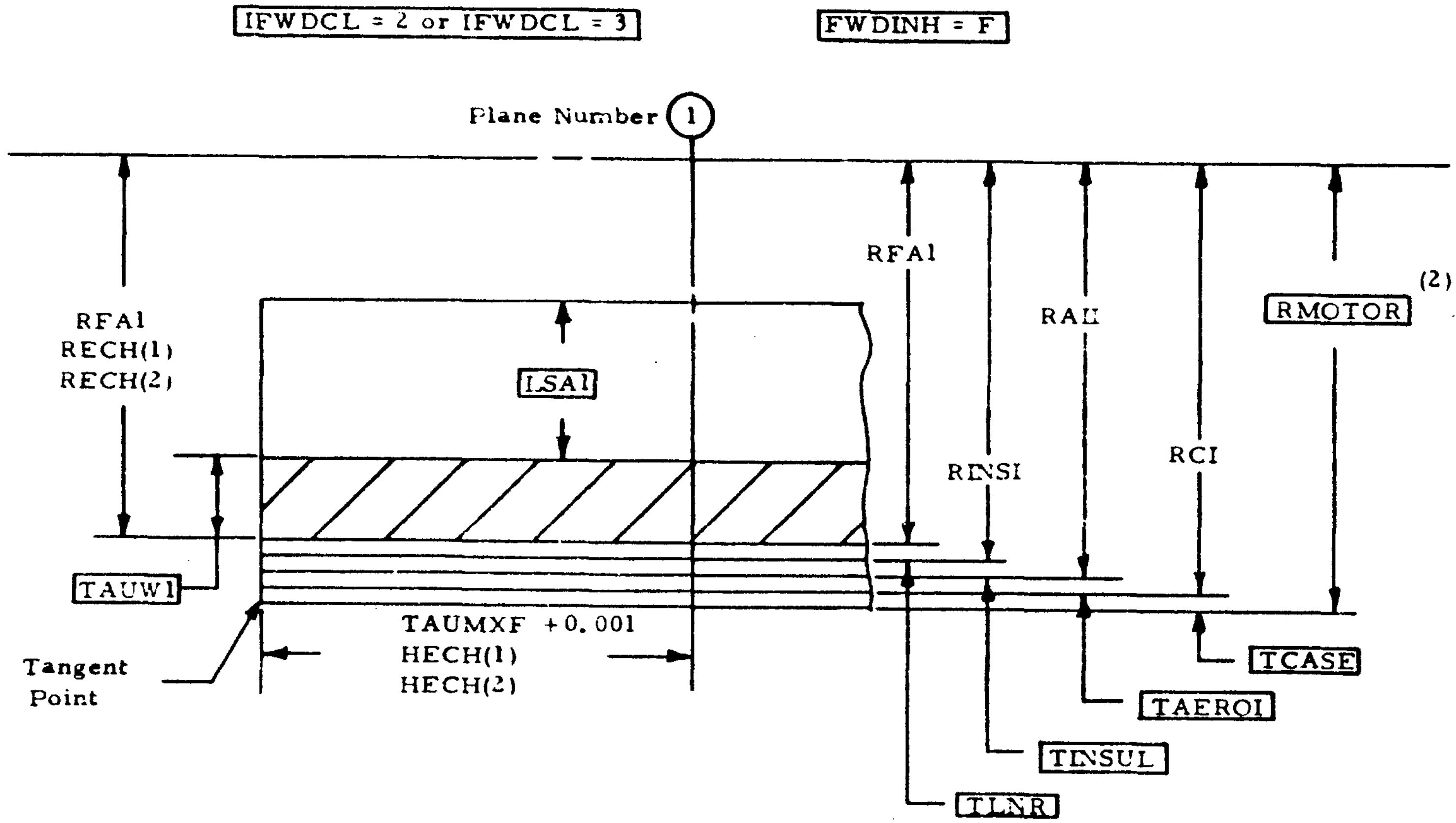
Figure 23. Nomenclature for Head-end of Grain Type 2, Forward Closure Type 1



NOTES

(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter

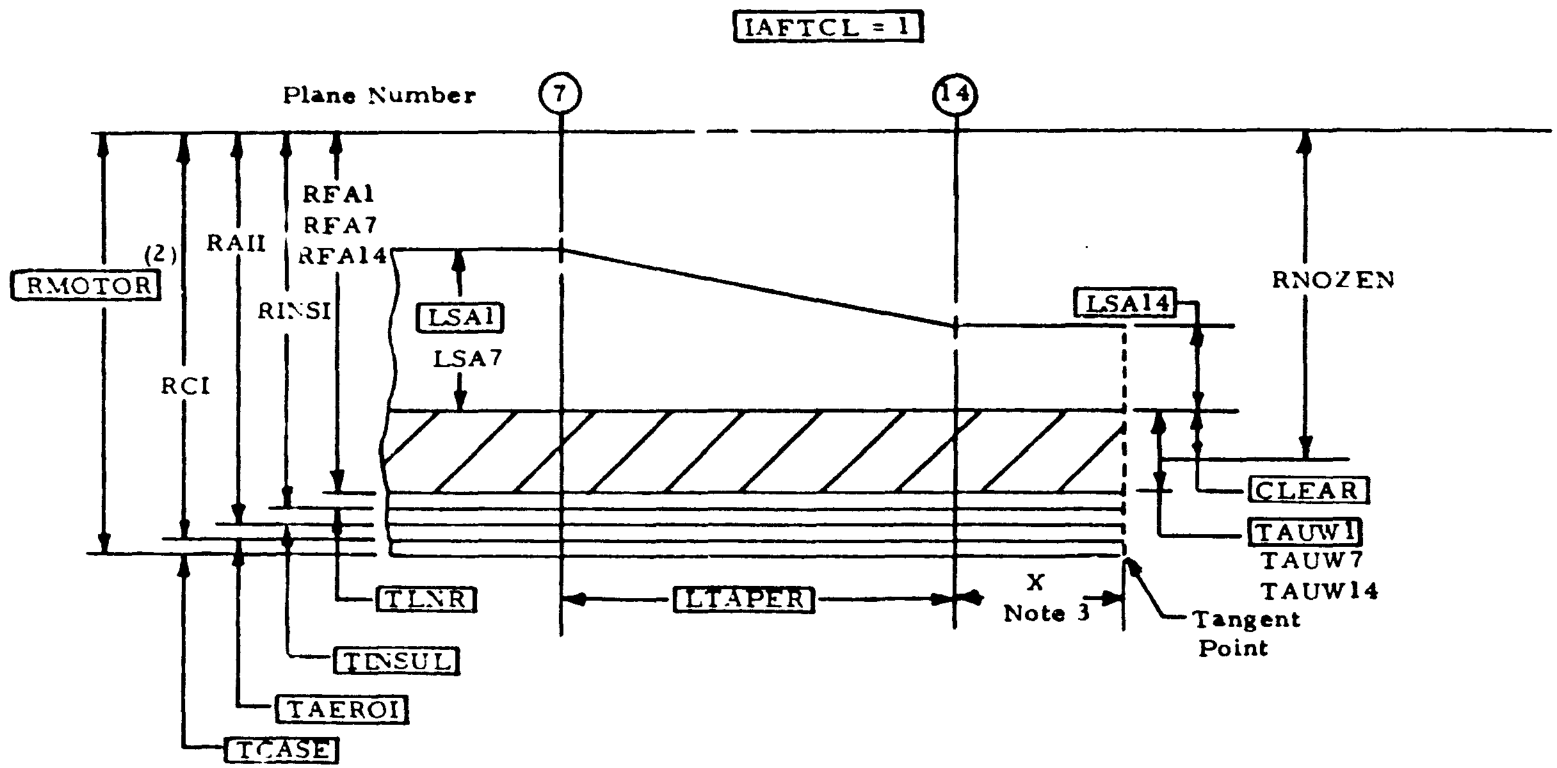
Figure 24. Nomenclature for Head-end of Grain Type 2, Forward Closure Type 2 or Type 3 (Inhibited)



NOTES

(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter

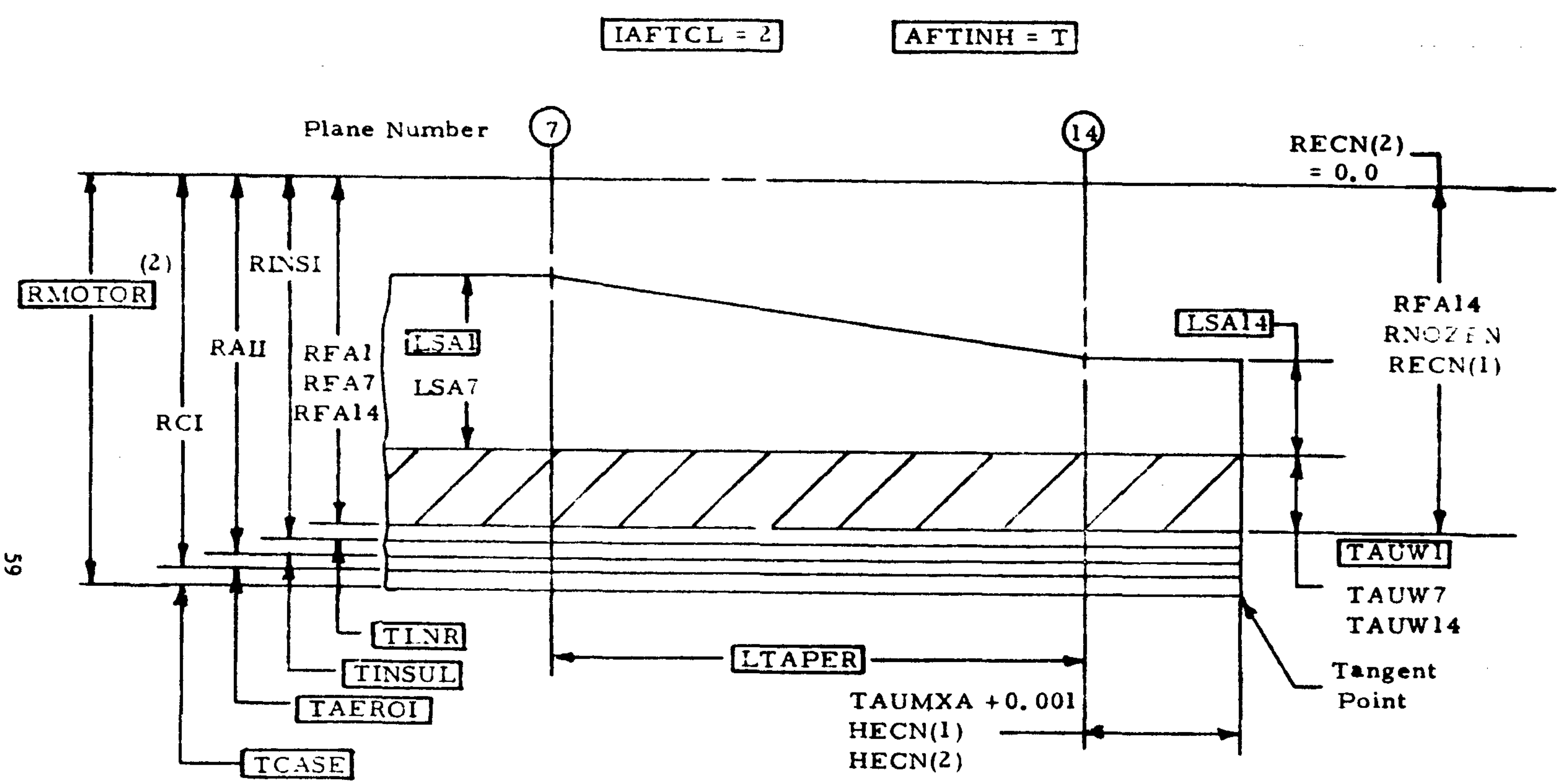
Figure 25. Nomenclature for Head-end of Grain Type 2, Forward Closure Type 2 or Type 3 (Not Inhibited)



NOTES

(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter
(3) X=(HECN(1)-X1A) if RFA14 < B5A; X=HECN(1) if RFA14 > B5A

Figure 26. Nomenclature for Aft End of Grain Type 2, Aft Closure Type 1



(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter

Figure 27. Nomenclature for Aft End of Grain Type 2, Aft Closure Type 2 (Inhibited)

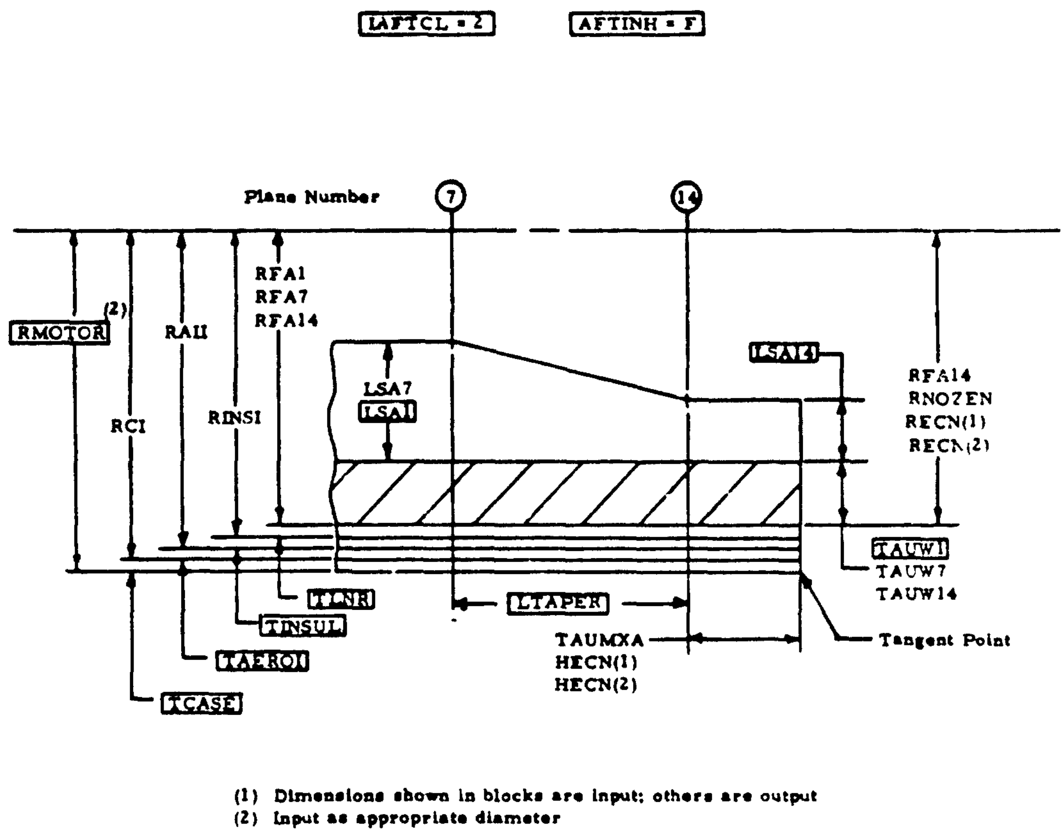
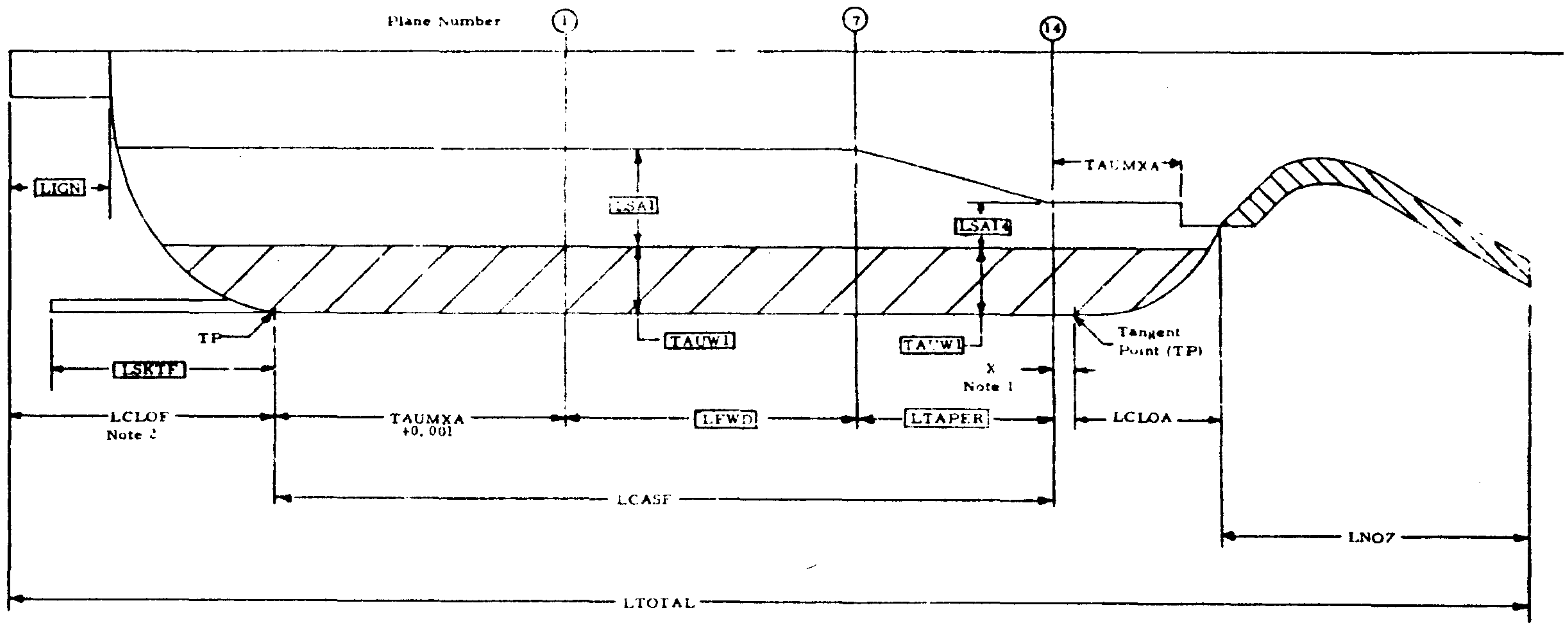


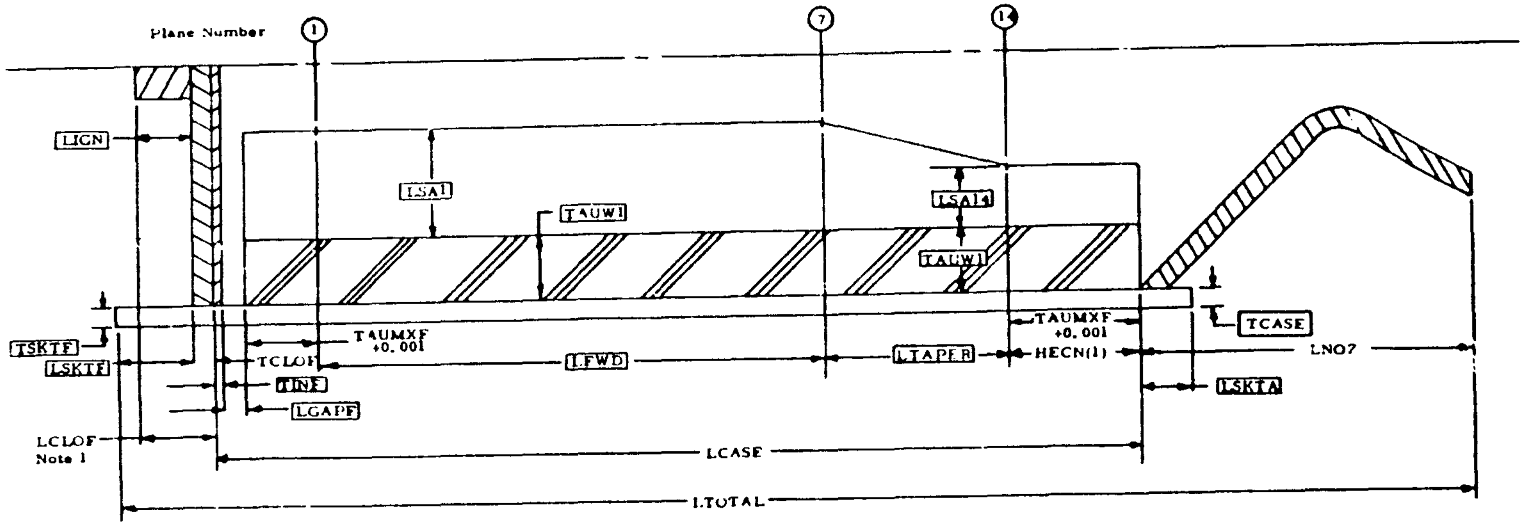
Figure 28. Nomenclature for Aft End of Grain Type 2, Aft Closure Type 2 (Not Inhibited)



NOTES

(1) For Aft Closure Type 1, X = (HECN(1)-X1A) if RFA14 < B5A, or is X = HFCN(1) if RFA14 ≥ B5A
(2) LSKTF used to calculate LTOTAL if LSKTF > LCLOF
(3) Dimensions shown in blocks are input; others are output

Figure 29. Nomenclature for Grain Type 2 with Aft Closure Type 1 and Forward Closure Type 1



NOTES

(1) LCLOF used to calculate LTOTAL if LCLOF > LSKTF

(2) Dimensions shown in blocks as input; others are output

Figure 30. Nomenclature for Grain Type 2 with Aft Closure Type 2 and Forward Closure Type 2 or Type 3

TABLE 7

OUTPUT OF GRAIN DIMENSION SETUP

GRAIN TYPE 2 - WAGON WHEEL

Parameter Name	Definition and Units
ALPHA	Included angle (deg) of propellant valley.
ALIA1-ALIA14	Included half-angle (deg) of propellent tip.
B5A	See Figure 10.
B5F	See Figure 6.
HECH(I)	Length (in) measured forward from Plane 1 to describe outside propellant surface in forward closure (I = 1, ... 5).
HECN(I)	Length (in) measured aft from Plane 14 to describe outside propellant surface in aft closure (I = 1, ... 5).
LAA1-LAA14	Length (in) of inner-most segment of propellant tip
LCASE	Length (in) of cylindrical portion of case.
LCLOA	Length (in) of aft elliptical closures from case-closure tangent point to aft most edge of stress-relief boot at RNOZEN.
LCLOF	Length (in) of forward closure from case-closure tangent point to forward face of igniter.
LFWD	Length (in) of forward untapered portion of grain.
LITD	Distance (in) across propellant valley for use in propellant structural analysis.
LSA1-LSA14	Height (in) of star tip at input planes, measured from web.
LSMAX	Maximum possible star tip height (in) for particular set of grain cross-section dimensions.
LSMIN	Minimum possible star tip height (in) for particular set of grain cross-section dimensions.
LTAPER	Length (in) of aft tapered portion of grain.
L7T1-L14T1	Length (in) from Plane 1 to downstream input planes (e.g., from Plane 7 to Plane 1, etc.).
OBCLR	Penalty for CLEAR greater than current TAUW1.
OBJLS	Penalty for LSA1 greater than LSMAX or less than LSMIN.

Table 7

OUTPUT OF GRAIN DIMENSION SETUP - GRAIN TYPE 2 (contd.)

Parameter Name	Definition and Units
OBJR5	Penalty for fillet radius R5A1 less than R5MIN or larger than R5MAX.
OBJTAU	Penalty for web thickness greater than input limit (WFLIM x RFA1) or less than zero.
OBLFWD	Penalty for LFWD less than zero.
OBLS14	Penalty for LSA14 greater than LSA1 or less than LSMIN.
OBLTPR	Penalty for LTAPER less than zero.
OBTCMN	Penalty for TCASE less than TFABC.
RAII	Inside radius (in) of aerodynamic heating insulation.
RCI	Inside radius (in) of case cylindrical section.
RECH(I)	Radii (in) describing outside propellant surface in forward closure (I = 1,... 5).
RECN(I)	Radii (in) describing outside propellant surface in aft closure (I=1,....5).
RFA1-RFA14	Fuel radius (in) at input planes.
RINSI	Inside radius (in) of case insulation.
RNOZEN	Radius (in) at aft end of case which is made compatible with the nozzle entrance radius (RN1).
R2A1-R2A14	Star tip radius (in) at input planes.
R5A1-R5A14	Fillet radius (in) between star tip and web at input planes.
R5MAX	Maximum possible fillet radius (in) R5 for particular set of grain cross-section dimensions.
R5MIN	Minimum possible fillet radius (in) R5 for particular set of grain cross-section dimensions.
TAUW1-TAUW14	Web thickness (in) at input planes.
TAUMXA	Maximum distance burned (in) at Plane 14.
TAUMXF	Maximum distance burned (in) at Plane 1.
THETA	Angle (deg) formed by grain cross-section symmetry (180/NSLOT)

Table 7

OUTPUT OF GRAIN DIMENSION SETUP - GRAIN TYPE 2 (contd.)

Parameter Name	Definition and Units
WA1-WA14	Actual separation distance (in) between adjacent star tips at input planes.
WAEROI	Weight (lb) of aerodynamic heating insulation.
WCASCY	Weight (lb) of cylindrical portion of case.
WEBFR	Web fraction at Plane 1 (TAUW1/RFA1).
WINA	Weight (lb) of insulation in aft closure.
WINF	Weight (lb) of insulation in forward closure.
WINSUI	Weight (lb) of all insulation in pressure vessel.
WINSCY	Weight (lb) of insulation in cylindrical portion of case.
WLNRA	Weight (lb) of liner in aft closure.
WLNRCY	Weight (lb) of liner in cylindrical portion of case.
WLNRF	Weight (lb) of liner in forward closure.
WSKTA	Weight (lb) of aft thrust skirt.
WSKTF	Weight (lb) of forward thrust skirt.
WSRBA	Weight (lb) of stress relief boot in aft closure.
WSRBF	Weight (lb) of stress relief boot in forward closure.
	See Figure 29.
X1A	See Figure 10.

NOTES

1. See Volume I for further illustrations of grain Type 2 dimensions.

GRAIN TYPE 3 - FINOCYL

This block of input data describes the finocyl (slots forward) grain configuration and the forward and aft closures. All data are contained in a single namelist GRAIN3.

The closure inputs are included in the input block for each grain type. However, the illustrations of the closures that show common parameters are included only in the grain Type 1 description.

Input data are provided to a subroutine SETUP3 that (1) confirms the geometric validity of all the grain dimensions (e.g., PATSH-adjusted lengths greater than zero, initial grain dimensions "close" properly, etc.); (2) checks dimensions against user-supplied limits (e.g., propellant web fraction less than limit, clearances between propellant and case greater than limit, etc.). (3) generates dimensions that describe propellant initial internal and external surfaces to the ballistic simulation module; (4) calculates all inert weights in the pressure vessel (except for pressure vessel closures, which is done after a design pressure is available from the ballistic simulation. The results of these analyses are given as part of this block of code output.

TABLE 8

NAMELIST/GRAIN 3

INPUTS FOR TYPE 3 GRAIN BALLISTIC SIMULATION

Parameter Name	Default Value	Definition and Units
ALPHA1	Note 1	Angle on side of longitudinal slot (deg).
BETA2A	0.0 Note 2	Ellipse ratio (major/minor) of inside surface of pressure vessel aft closure Type 1.
BETA2F	0.0 Note 2	Ellipse ratio (major/minor) of inside surface of pressure vessel forward closure Type 1.
CLEAR	0.0	Radial clearance (in) between port radius and radius of aft closure opening on aft closure Type 1. Positive number when port is smaller than opening.
DELAI	0.0	Density (lbm/cu in) of insulation to protect grain against aerodynamic heating.
DELCAS	0.0	Density (lbm/cu in) of pressure vessel (case cylindrical section and integral closures).
DELCLO	0.0	Density (lbm/cu in) of Type 2 forward closure.
DELINS	0.0	Density (lbm/cu in) of case internal insulation.
DELLNR	0.0	Density (lbm/cu in) of liner.
DELSRB	0.0	Density (lbm/cu in) of stress relief boot.
DMOTOR	Note 1	Outside diameter (in) of motor.
LCONE	Note 1	Length (in) of coned portion of grain.
LCP	Note 1	Length (in) of cylindrically perforated (CP) portion of grain.
LGAPF	0.0	Length (in) between forward face of grain and aft face of insulation on Forward Closure Types 2 or 3.
LIGN	0.0	Length (in) of igniter and/or safe-and-arm device that extends forward of the outside surface of the forward closure.
LSKTA	0.0	Length (in) of aft thrust skirt
LSKTF	0.0	Length (in) of forward thrust skirt.
LSLOT	Note 1	Length (in) of slotted portion of grain.

Table 8

NAMELIST/GRAIN 3 (contd.)

Parameter Name	Default Value	Definition and Units
MINWEB	0.0	Minimum allowed radial thickness (in) of propellant between slot tip and inside surface of liner.
NSLOTS	Note 1	Integer to specify number of longitudinal slots in grain.
RIGN	0.0	Minimum radius (in) of port to allow for igniter and for gas flow passage.
R2A1	Note 1	Port radius (in) R2 at Plane 1.
R2A14	Note 1	Port radius (in) R2 at Plane 14.
R4A1	Note 1	Slot fillet radius (in) R4 at Plane 1.
R4MIN	0.0	Minimum allowed slot fillet radius, R4A1 (in).
R5A1	Note 1	Slot depth radius (in) R5 at Plane 1.
TAEROI	0.0	Thickness (in) of insulation to protect grain against aerodynamic heating.
TCASE	Note 1	Thickness (in) of pressure vessel cylindrical section.
TFABC	0.0	Minimum allowed thickness (in) of case cylindrical section due to fabrication considerations.
THTRAN	Note 1	Angle (deg) of the "bottom" of the longitudinal slots in the transition from slots to CP, measured from motor centerline. Must be less than 90 deg.
TINAMN	0.0	Thickness (in) of insulation in aft closure Type 1, measured at tangent point of closure and case cylindrical section.
TINAMX	0.0	Thickness (in) of insulation in aft closure Type 1, measured at opening of closure (where nozzle attaches).
TINCON	Note 1	Thickness (in) of insulation under the coned aft grain section, measured at Plane 14.
TINF	0.0	Thickness (in) of insulation on flat plate forward closures (Type 2 or Type 3).
TINFMN	0.0	Thickness (in) of insulation in forward closure Type 1, measured at tangent point of closure and case cylindrical section.

Table 8

NAMELIST/GRAIN 3 (contd.)

Parameter Name	Default Value	Definition and Units
TINFMX	Note 2	Thickness (in) of insulation in forward closure Type 1, measured at RIGN radius.
TINSLT	Note 1	Thickness (in) of insulation under the slotted forward grain section, measured at Plane 1.
TLNR	0.0	Thickness (in) of liner, constant over entire interior surface.
TSKTA	0.0	Thickness (in) of aft thrust skirt.
TSKTF	0.0	Thickness (in) of forward thrust skirt.
TSRBA	0.0	Thickness (in) of stress relief boot in aft closure Type 1, measured at aft case opening.
TSRBF	0.0	Thickness (in) of stress relief boot in forward closure Type 1, measured at RIGN radius.
WFLIM	1.0	Maximum allowed web fraction at Plane 8 and 10.
FDMTR	T	Search control for motor outside diameter (DMOTOR). See Note 3.
FLCONE	T	Search Control for length of coned portion of grain (LCONE). See Note 3.
FLCP	T	Search control for length of cylindrically perforated (CP) portion of grain (LCP). See Note 3.
FLSLOT	T	Search control for length of slotted portion of grain (LSLOT) See Note 3.
FR2A1	T	Search control for port radius R2 at Plane 1. See Note 3.
FR2A14	T	Search control for port radius R2 at Plane 14. See Note 3.
FR4A1	T	Search control for slot fillet radius R4 at Plane 1. See Note 3.
FR5A1	T	Search control for slot depth radius R5 at Plane 1. See Note 3.
FTCASE	T	Search control for case wall thickness TCASE in cylindrical section. See Note 3.

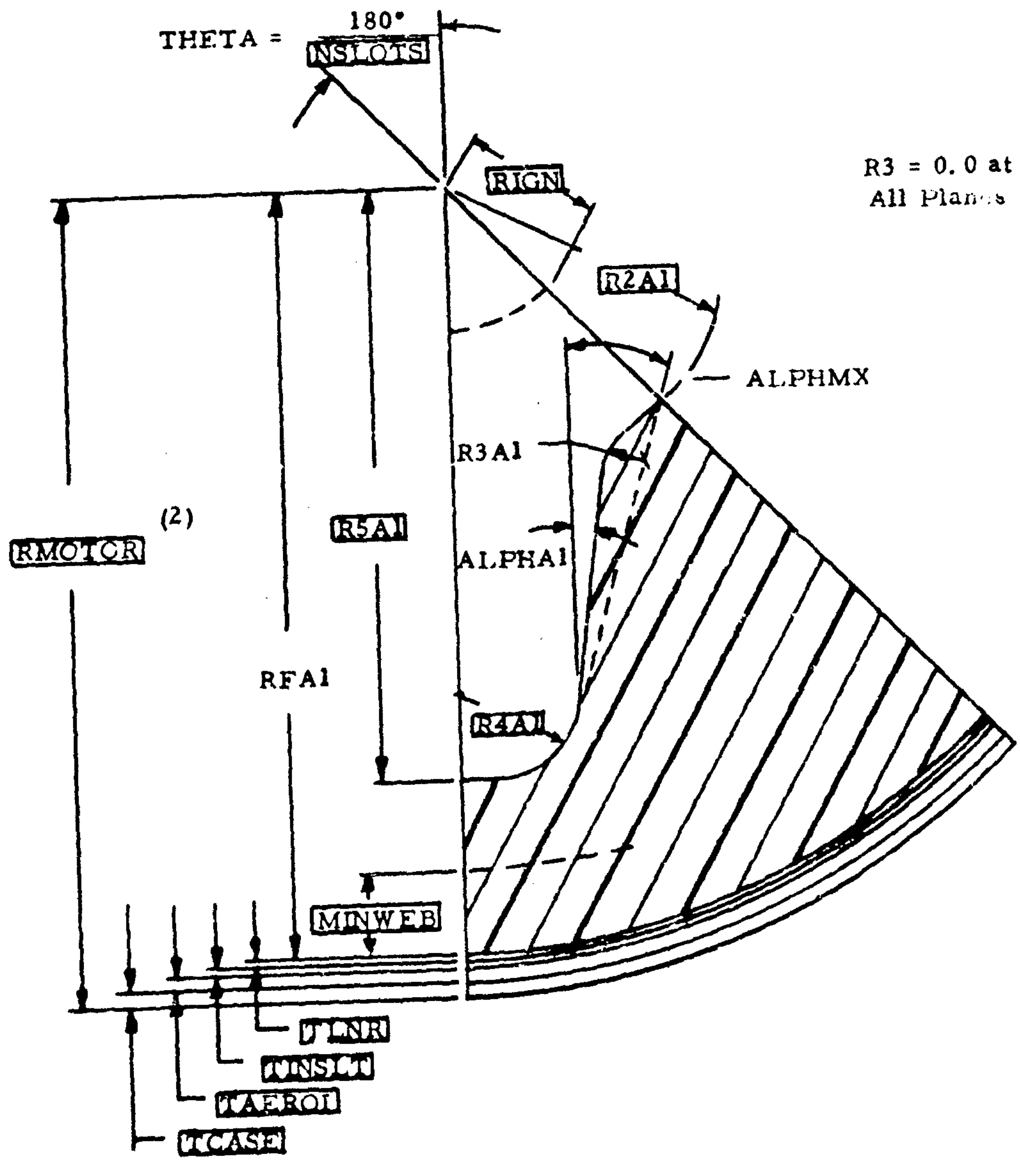
Table 8

NAMELIST/GRAIN 3 (contd.)

Parameter Name	Default Value	Definition and Units
TPRDIN	T	Insulation under coned aft grain section tapers from thickness TINCON at Plane 14 to zero thickness at Plane 10/11 (T = yes, F = no).

NOTES

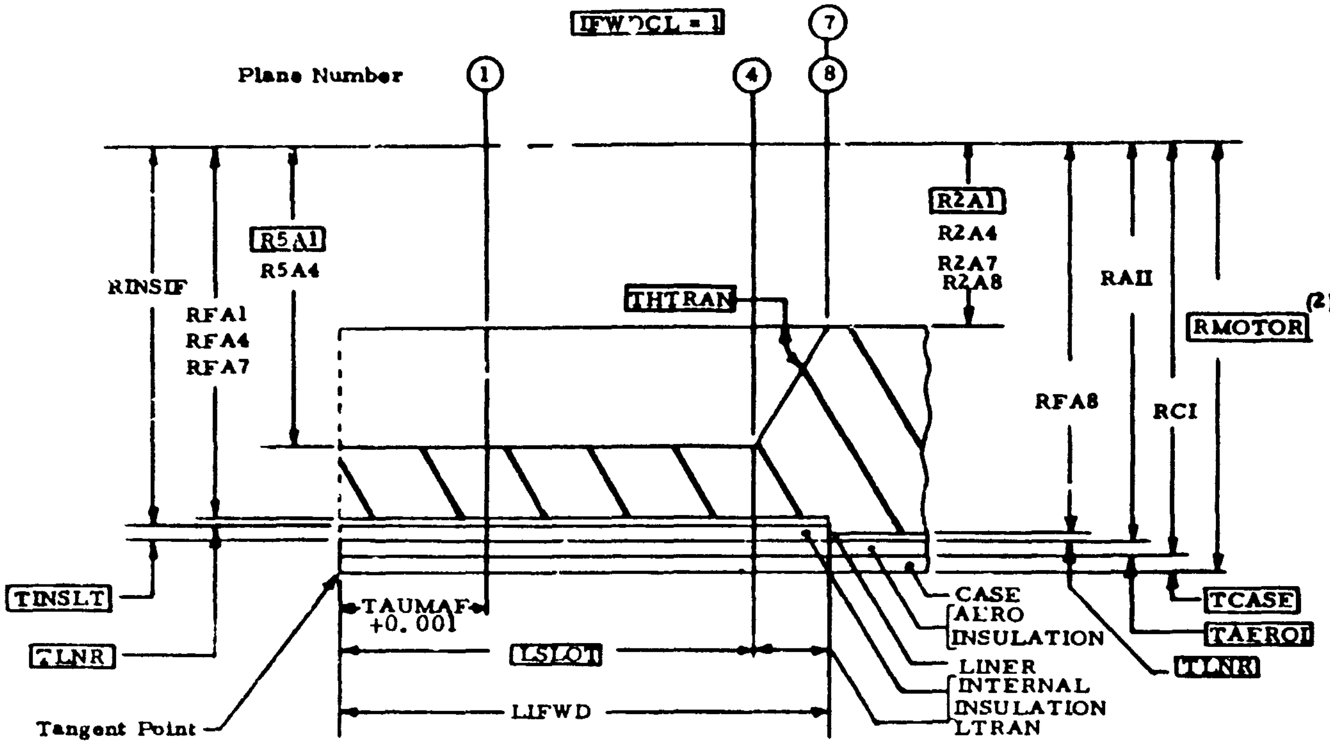
1. Input required for all problems
2. Input required for all problems with forward closure Type 1.
3. Logical command to specify parameters that may be adjusted during optimization search. T = parameter will be maintained constant at input value; F = parameter will not be maintained at input value, but will be adjusted.



NOTES:

(1) Dimensions in blocks are input; others are output
(2) Input as appropriate diameter

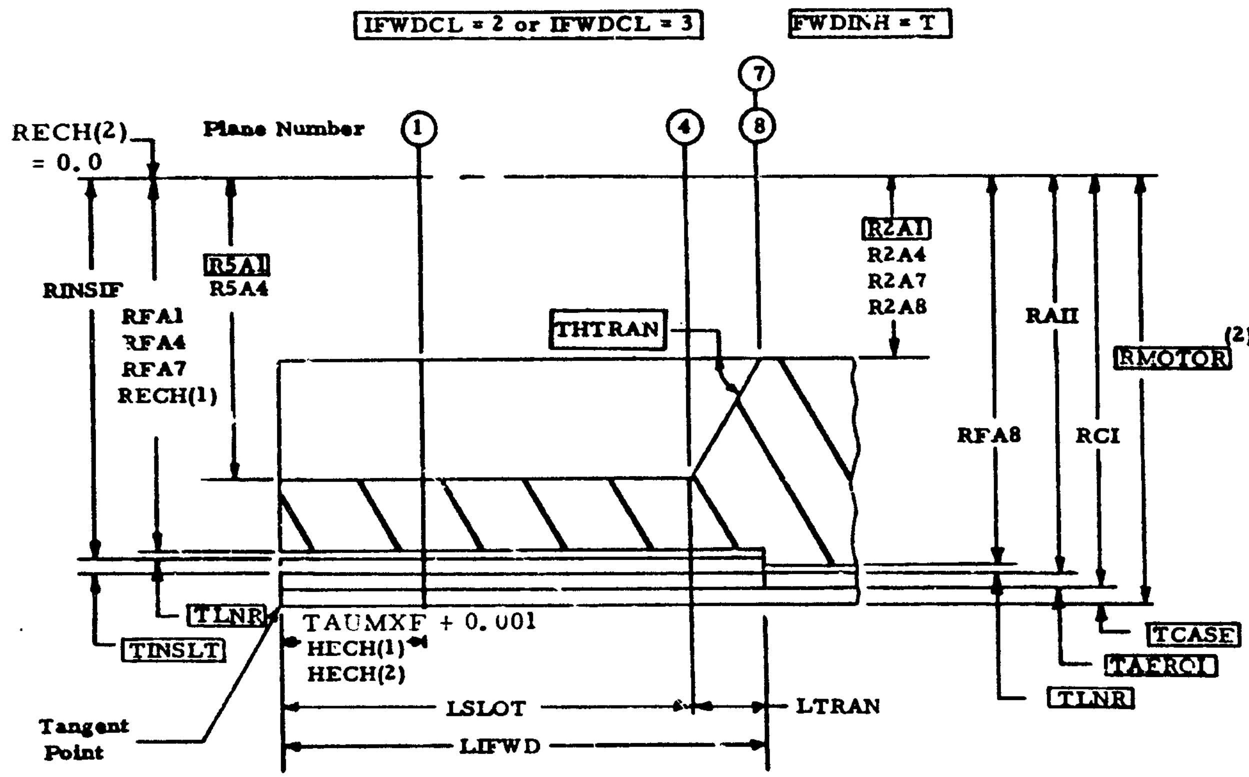
Figure 31. Grain Type 3 Cross-Section at Plane 1



NOTES:

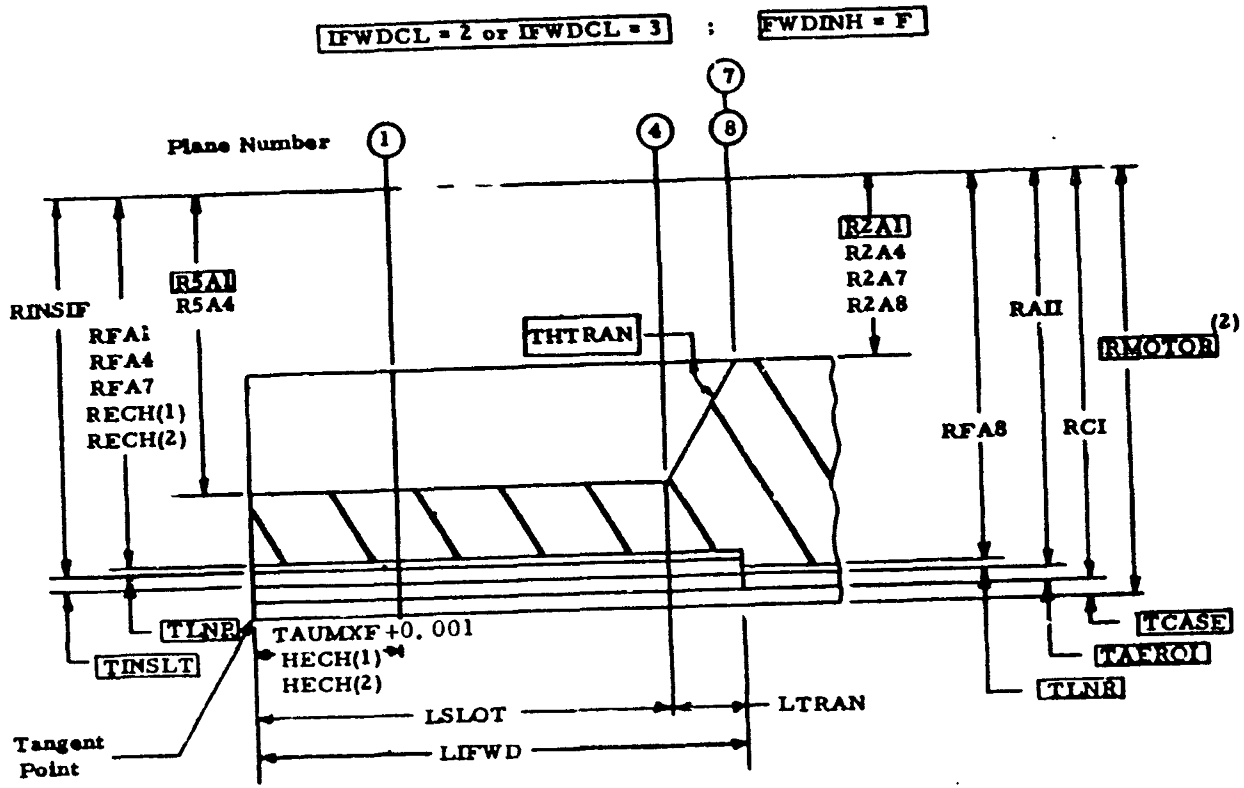
(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter

Figure 32. Nomenclature for Head-end of Grain Type 3, Forward Closure Type 1



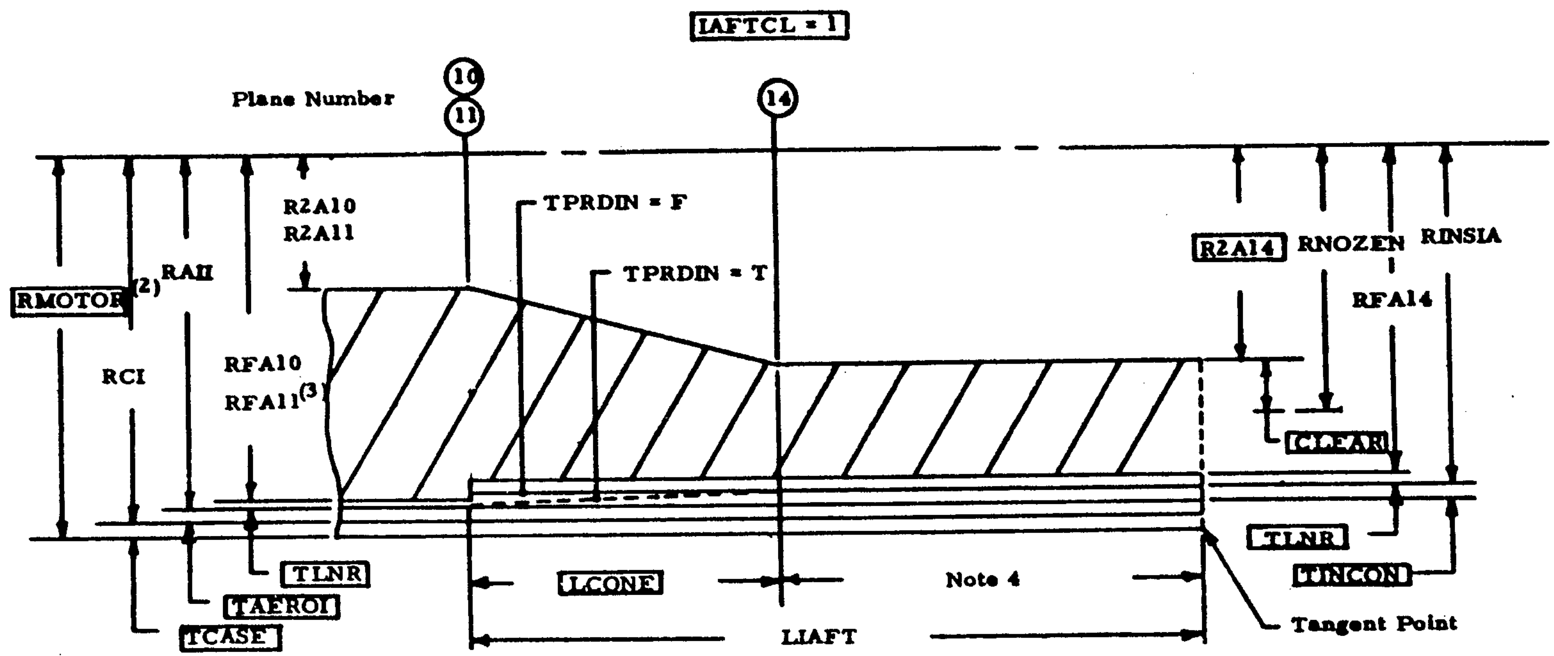
(1) Dimensions shown in blocks are input; others are output
(2) Input as Appropriate diameters

Figure 33. Nomenclature for Head-end of Grain Type 3, Forward Closure Type 2 or Type 3 (Inhibited)



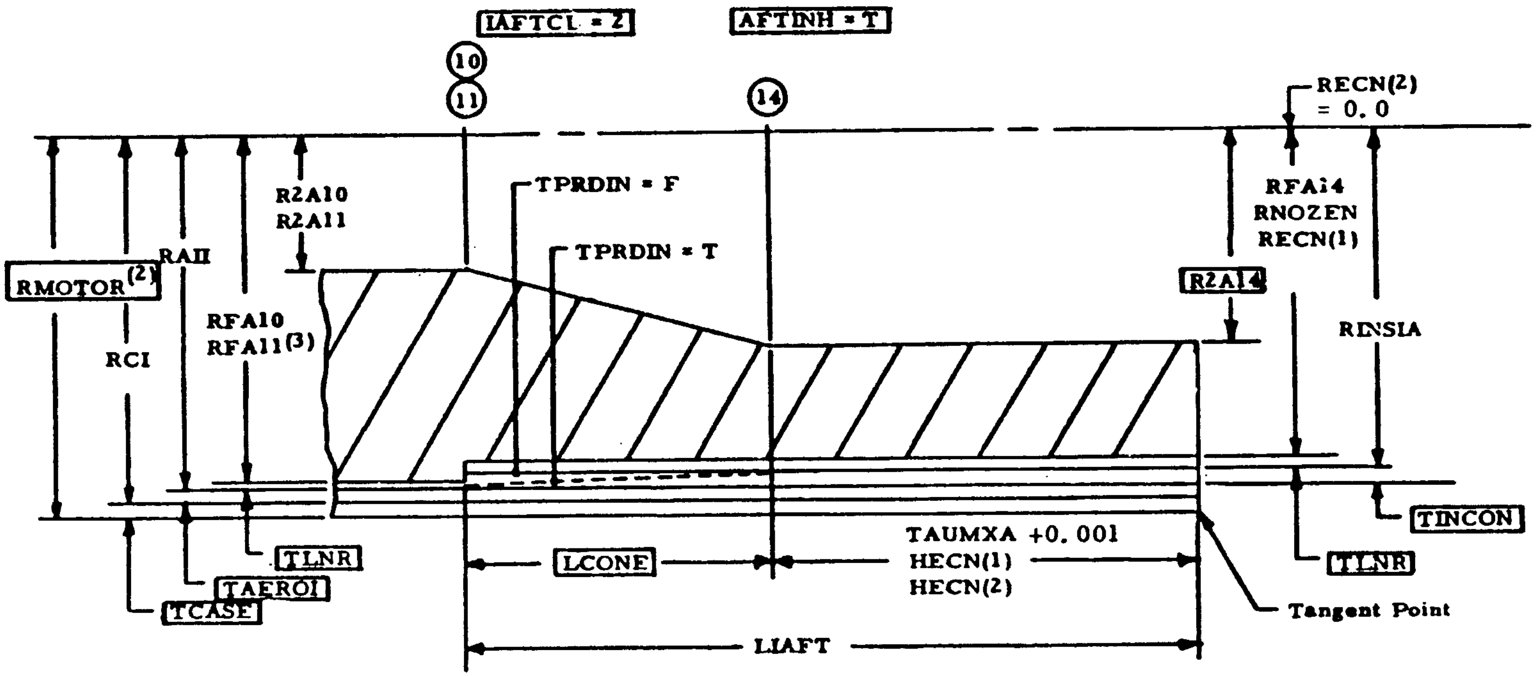
(1) Dimensions shown in blocks are input; others are output
(2) Input as Appropriate diameters

Figure 34. Nomenclature for Head-end of Grain Type 3, Forward Closure Type 2 or Type 3 (Not Inhibited)



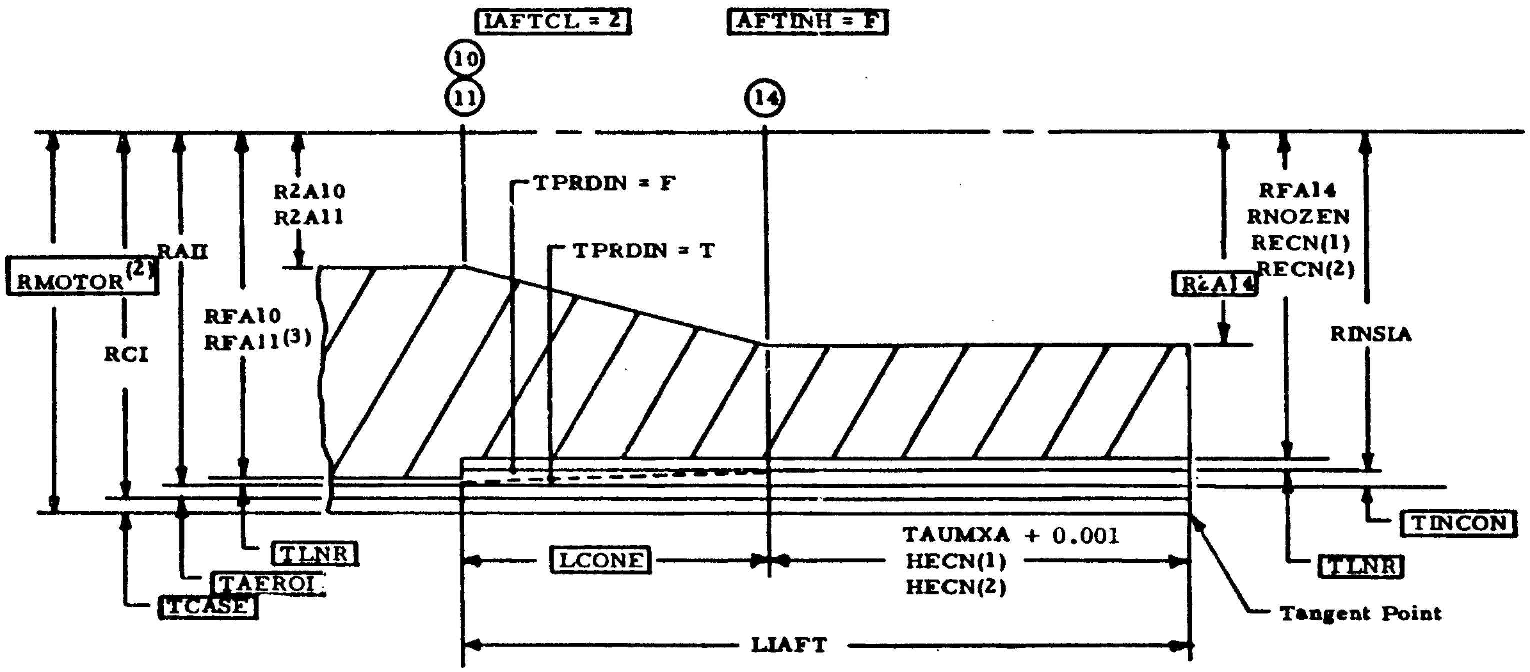
(1) Dimensions shown in blocks are input; others are output.
(2) Input as appropriate diameter.
(3) RFA11 = RFA10 if TPRDIN = T; RFA11 = RFA10 - TINCON if TPRDIN = F
(4) (HECN(1) - X1A if RFA14 < B5A, or HECN(1) if RFA14 $\geq$ B5A

Figure 35. Nomenclature for Aft End of Grain Type 3, Aft Closure Type 1



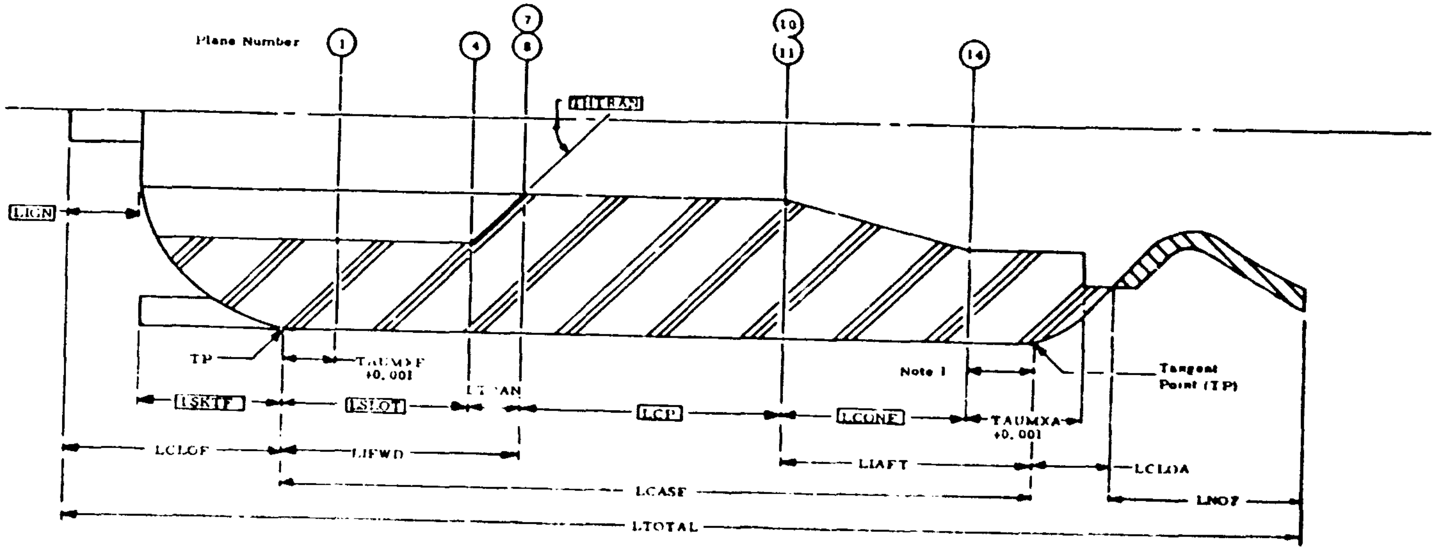
(1) Dimensions shown in blocks are input; others are output.
(2) Input as appropriate diameter.
(3) RFA11 = RFA10 if TPRDIN = T; RFA11 = RFA10 - TINCON if TPRDIN = F

Figure 36. Nomenclature for Aft End of Grain Type 3, Aft Closure Type 2 or Type 3 (Inhibited)



(1) Dimensions shown in blocks are input; others are output.
(2) Input as appropriate diameter.
(3) RFA11 = RFA10 if TPRDIN = T; RFA11 = RFA10 - TINCON if TPRDIN = F

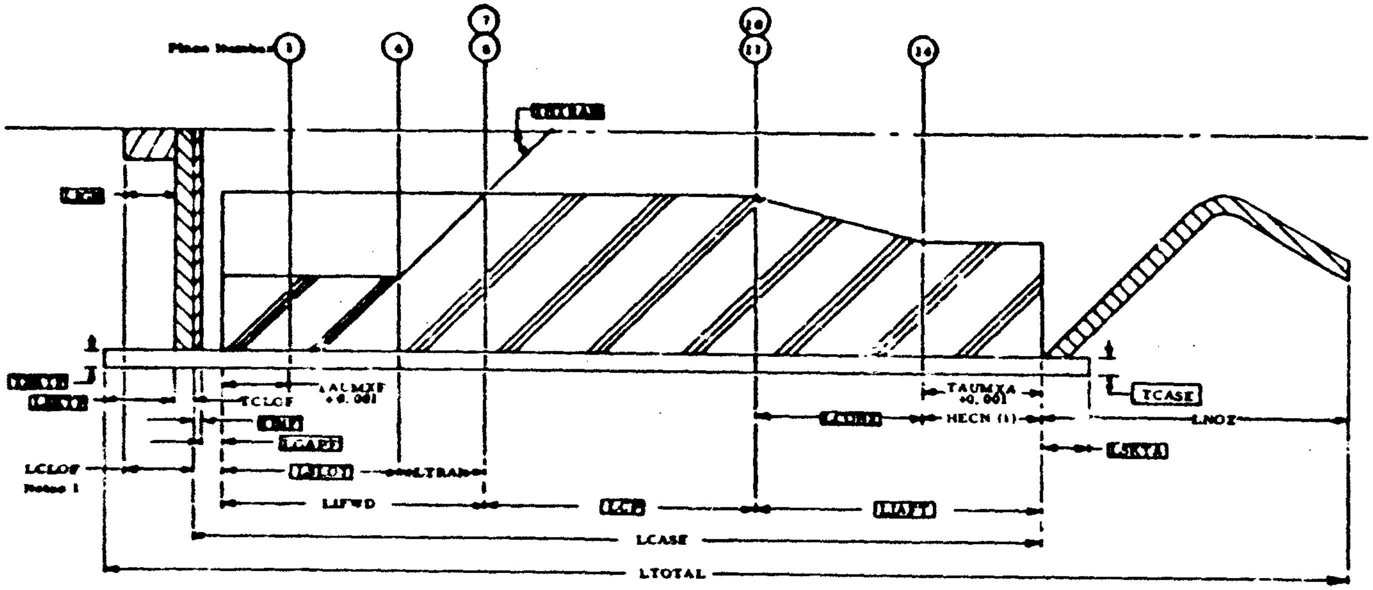
Figure 37. Nomenclature for Aft End of Grain Type 3, Aft Closure Type 2 or Type 3 (Not Inhibited)



NOTES

(1) For Aft Closure Type 1, this dimension is (HECN(1)-X1A) if RFAI4 < B5A, or is HECN (1) if RFAI4 > LCLOF
(2) LSKTF used to calculate LTOTAL if LSKTF > LCLOF
(3) Dimensions shown in blocks are input; others are output

Figure 38. Nomenclature for Grain Type 3 With Aft Closure Type 1 and Forward Closure Type 1



NOTES

(1) LCLOF used to calculate LTOTAL if LCLOF > LSKTF
(2) Dimensions shown in blocks as input; others are output

Figure 39. Nomenclature For Grain Type 3 With Aft Closure Type 2 and Forward ClosureType 2 or 3

TABLE 9

OUTPUT OF GRAIN DIMENSION SETUP

GRAIN TYPE 3 - FINOCYL

Parameter Name	Definition and Units
ALPHA1-14	Angle (deg) on side of longitudinal slot at input planes
ALPHMX	Maximum allowed angle (deg) on side of longitudinal slot for given combination of dimensions
HECH(I)	Length (in) measured forward from Plane 1 to describe outside propellant surface in forward closure (I=1,....5)
HECN(I)	Length (in) measured aft from Plane 14 to describe outside propellant surface in aft closure (I=1,....5)
LCASE	Length (in) of cylindrical portion of case
LCLOA	Length (in) of aft elliptical closures from case-closure tangent point to aft most edge of stress-relief boot at RNOZEN.
LCLOF	Length (in) of forward closure from case-closure tangent point to forward face of igniter.
LIAFT	Length (in) of insulation under coned portion of grain
LIFWD	Length (in) of insulation under longitudinal slots and transition
LTOTAL	Intermediate report of motor length (in), consisting of forward and aft closures and cylindrical section
LTRAN	Length (in) of transition section between slotted section and cylindrically perforated (CP) section
L4T1-L14T1	Length (in) from Plane 1 to downstream input planes
OBALMX	Penalty for angle on sides of slots (ALPHA1) greater than maximum permissible for given grain dimensions.
OBJLCP	Penalty for LCP less than zero
OBJWF	Penalty for web fraction greater than input limit (WFLIM)
OBLCON	Penalty for LCONE less than zero
OBR2MN	Penalty for R2A1 less than either RIGN or R4MIN
OBR4MN	Penalty for R4A1 less than input R4MIN
OBR5MX	Penalty for R5A1 greater than (RFA1-MINWEB)

Table 9

OUTPUT OF GRAIN DIMENSION SETUP - GRAIN TYPE 3 (contd.)

Parameter Name	Definition and Units
OBR2T4	Penalty for (R5A1-R2A1-R4A1) less than zero (Test No. 4). See Note 1.
OBR2T5	Penalty for (RFA1-R2A1-R4A1-MINWEB) less than zero (Test No. 5). See Note 2.
OBR4T4	Penalty for (R5A1-R2A1-R4A1) less than zero (Test No. 4). See Note 1.
OBR4T5	Penalty for (RFA1-R2A1-R4A1-MINWEB) less than zero (Test No. 5). See Note 2.
OBR4T6	Penalty for R4A1 greater than R2A1 (Test No. 6) when R4A1 is adjusted to correct discrepancy.
OBR5T4	Penalty for (R5A1-R2A1-R4A1) less than zero (Test No. 4). See Note 1.
OBR2T6	Penalty for R4A1 greater than R2A1 (Test No. 6) when R2A1 is adjusted to correct discrepancy
OBR5T7	Penalty for (RFA1-R2A1-R4A1) less than zero (Test No. 7).
OBR2T9	Penalty for R2A14 less than R2A11 (Test No. 9).
OBSLOT	Penalty for LSLOT less than zero
OBTCMN	Penalty for TCASE less than TFABC
OR2T11	Penalty for R2A14 greater than (RFA14-CLEAR). Test No. 11
RAII	Inside radius (in) of aerodynamic heating insulation
RCI	Inside radius (in) of case cylindrical section
RECH(I)	Radii (in) describing outside propellant surface in forward closure (I=1,...5)
RECN(I)	Radii (in) describing outside propellant surface in aft closure (I=1,....5)
RFA1-14	Fuel radius (in) at input planes
RINSIA	Inside radius (in) of case insulation at aft end
RINSIF	Inside radius (in) of case insulation at forward end
RNOZEN	Radius (in) at aft end of case which is made compatible with the nozzle entrance radius (RN1)

Table 9

OUTPUT OF GRAIN DIMENSION SETUP - GRAIN TYPE 3 (contd.)

Parameter Name	Definition and Units
R2A1 - R2A14	Port radius (in) at input planes
R3A1 - R3A14	Corner radius (in) at input planes, always equal to zero.
R4A1 - R4A14	Slot fillet radius (in) at bottom of slot at input planes
R4A1MX	Maximum possible R4A1 slot fillet radius (in) at Plane 1; must be greater than input R4MIN or no solution exists.
R5A1 - R5A14	Slot depth radius (in) at input planes
TAUMXA	Maximum distance burned (in) at Plane 14 (RFA14-R2A14).
TAUMXF	Maximum distance burned (in) at Plane 1 (RFA1-R2A1).
WAEROI	Weight (lb) of aerodynamic heating insulation
WCASCY	Weight (lb) of cylindrical portion of case
WEBFR	Web fraction (RFA8-R2A8)/RFA8)
WINA	Weight (lb) of insulation in aft closure
WINCON	Weight (lb) of insulation under coned portion of grain
WINERT	Intermediate report of inert weight (lb), consisting of liner, insulation and stress relief boots
WINF	Weight (lb) of insulation in forward closure
WINSL	Weight (lb) of insulation under slots
WINSCY	Weight (lb) of all insulation in cylindrical portion of case (WINSL, WINCON)
WLNRA	Weight (lb) of liner in aft closure
WLNRCN	Weight (lb) of liner for coned portion of grain
WLNRCP	Weight (lb) of liner for CP portion of grain
WLNRCY	Weight (lb) of all liner in cylindrical portion of case (WLNRSL, WLNRCP, WLNRCN)
WLNRF	Weight (lb) of liner in forward closure.
WLNRSL	Weight (lb) of liner for slotted portion of grain
WSKTA	Weight (lb) of aft thrust skirt
WSKTF	Weight (lb) of forward thrust skirt

Table 9

OUTPUT OF GRAIN DIMENSION SETUP - GRAIN TYPE 3 (contd.)

Parameter Name	Definition and Units
WSRBA	Weight (lb) of stress relief boot in aft closure
WSRBF	Weight (lb) of stress relief boot in forward closure

NOTES

1. These penalties are calculated when (R5A1-R2A1-R4A1) is less than zero but the incompatibility cannot be removed by changing any single one of the three variables. Each is individually changed (in the order R4A1, R2A1, R5A1) until the incompatibility is removed or the particular variable reaches another limit, with a penalty being calculated for each change, respectively.

2. These penalties are calculated when (RFA11-R2A11-R4A1-MINWFB) is less than zero, but the incompatibility cannot be removed by changing any single one of the two available variables (R4A1 and R2A1). Each is individually changed (in the order R4A1, R2A1) until the incompatibility is removed or the particular variable reaches another limit, with a penalty being calculated for each change, respectively.

GRAIN TYPE 4 - CONOCYL

This block of input data describes the conocyl grain configuration and the forward and aft closures. All data are contained in a single namelist GRAIN4.

The closure inputs are included in the input block for each grain type. However, the illustrations of the closures that show common parameters are included only in the grain Type 1 description.

Input data are provided to a subroutine SETUP4 that (1) confirms the geometric validity of all the grain dimensions (e.g., PATCH-adjusted lengths greater than zero, initial grain dimensions "close" properly, etc.); (2) checks dimensions against user-supplied limits (e.g., propellant web fraction less than limit, clearances between propellant and case greater than limit, etc.); (3) generates dimensions that describe propellant initial internal and external surfaces to the ballistic simulation module; (4) calculates all inert weights in the pressure vessel (except for pressure vessel closures, which is done after a design pressure is available from the ballistic simulation. The results of these analyses are given as part of this block of code output.

TABLE 10

NAMELIST/GRAIN4

INPUTS FOR TYPE 4 GRAIN BALLISTIC SIMULATION

Parameter Name	Default Value	Definitions and Units
BETA2A	0.0 Note 3	Ellipse ratio (major/minor diameter) of inside surface of pressure vessel aft closure Type 1.
BETA2F	0.0 Note 2	Ellipse ratio (major/minor diameter) of inside surface of pressure vessel forward closure Type 1.
CLEAR	0.0	Radial clearance (in) between port radius and radius of aft closure opening for aft closure Type 1. Positive when port is smaller than opening.
DELAI	0.0	Density (lbm/cu in) of insulation to protect propellant grain against aerodynamic heating.
DELCAS	0.0	Density (lbm/cu in) of pressure vessel (case cylindrical section and integral closures).
DELINS	0.0	Density (lbm/cu in) of case internal insulation.
DELLNR	0.0	Density (lbm/cu in) of liner.
DELSRB	0.0	Density (lbm/cu in) of stress relief boot.
DMOTOR	Note 1	Outside diameter (in) of motor.
LCONE	Note 1	Length (in) of aft coned portion of grain.
LCP	Note 1	Length (in) of cylindrically perforated (CP) portion of grain.
LH	0.0	Length (in) of forward propellant segment.
LIGN	0.0	Length (in) of igniter and/or safe-and-arm device that extends forward of the outside surface of the forward closure.
LSKTA	0.0	Length (in) of aft thrust skirt.
LSKTF	0.0	Length (in) of forward thrust skirt.
RIGN	0.0	Minimum radius (in) of port in forward propellant segment to allow for igniter and for gas flow passage.
RTIP	Note 1	Outboard radius (in) of slot.
R1	Note 1	Fillet radius (in) of slot.
R2A3	Note 1	Port radius (in) R2 at Plane 3.

Table 10

NAMELIST/GRAIN4 (contd.)

Parameter Name	Default Value	Definitions and Units
R2A14	Note 1	Port radius (in) R2 at Plane 14.
TAEROI	0.0	Thickness (in) of insulation to protect grain against aerodynamic heating.
TCASE	Note 1	Thickness (in) of pressure vessel (case) cylindrical section.
TFABC	0.0	Minimum allowed thickness (in) of case cylindrical section due to fabrication considerations.
TINAMN	0.0	Thickness (in) of insulation in aft closure Type 1, measured at tangent point of closure and case cylindrical section.
TINAMX	0.0	Thickness (in) of insulation in aft closure Type 1 measured at opening of closure (where nozzle attaches).
TINCA	0.0	Thickness (in) of insulation at Plane 14.
TINCF	0.0	Thickness (in) of insulation at Plane 1.
TINFMN	0.0	Thickness (in) of insulation in forward closure Type 1, measured at tangent point of closure and case cylindrical section.
TINFMX	0.0	Thickness (in) of insulation in forward closure Type 1, measured at RIGN radius.
TINMXA	0.0	Thickness (in) of insulation at aft end of grain with aft closure Type 2 and when aft propellant face is not inhibited (AFTINH = F).
TLNR	0.0	Thickness (in) of liner, constant over entire interior surface.
TSKTA	0.0	Thickness (in) of aft thrust skirt.
TSKTF	0.0	Thickness (in) of forward thrust skirt.
TSRBA	0.0	Thickness (in) of stress relief boot in aft closure Type 1, measured at aft case opening.
WFLIM	1.0	Maximum allowed web fraction at Plane 5.

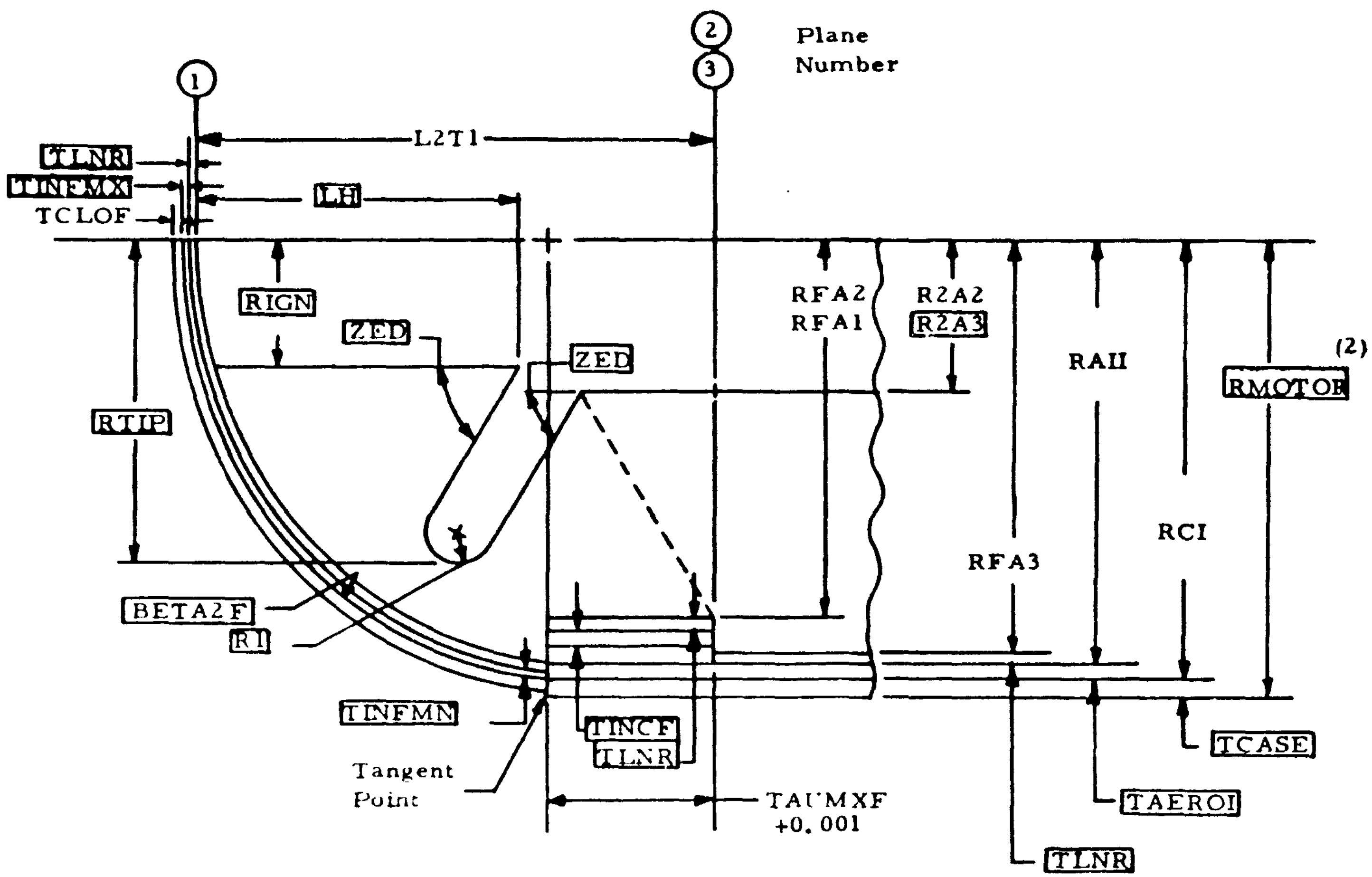
Table 10

NAMELIST/GRAIN4 (contd.)

Parameter Name	Default Value	Definitions and Units
ZED	Note 1	Angle (deg) of slot with motor centerline; $45 < ZED < 90$.
FDMTR	T	Search control for motor outside diameter (DMOTOR). See Note 4.
FLCONE	T	Search control for length of aft coned portion of propellant grain (LCONE). See Note 4.
FLCP	T	Search control for length of cylindrically perforated (CP) portion of propellant grain (LCP). See Note 4.
FLH	T	Search control for length of forward propellant segment (LH). See Note 4.
FRTIP	T	Search control for outboard radius of slot (RTIP). See Note 4.
FR2A3	T	Search control for port radius R2 at Plane 3. See Note 4.
FR2A14	T	Search control for port radius R2 at Plane 14. See Note 4.
FTCASE	T	Search control for case wall thickness in cylindrical section (TCASE). See Note 4.
FZED	T	Search control for angle of slot (ZED). See Note 4.

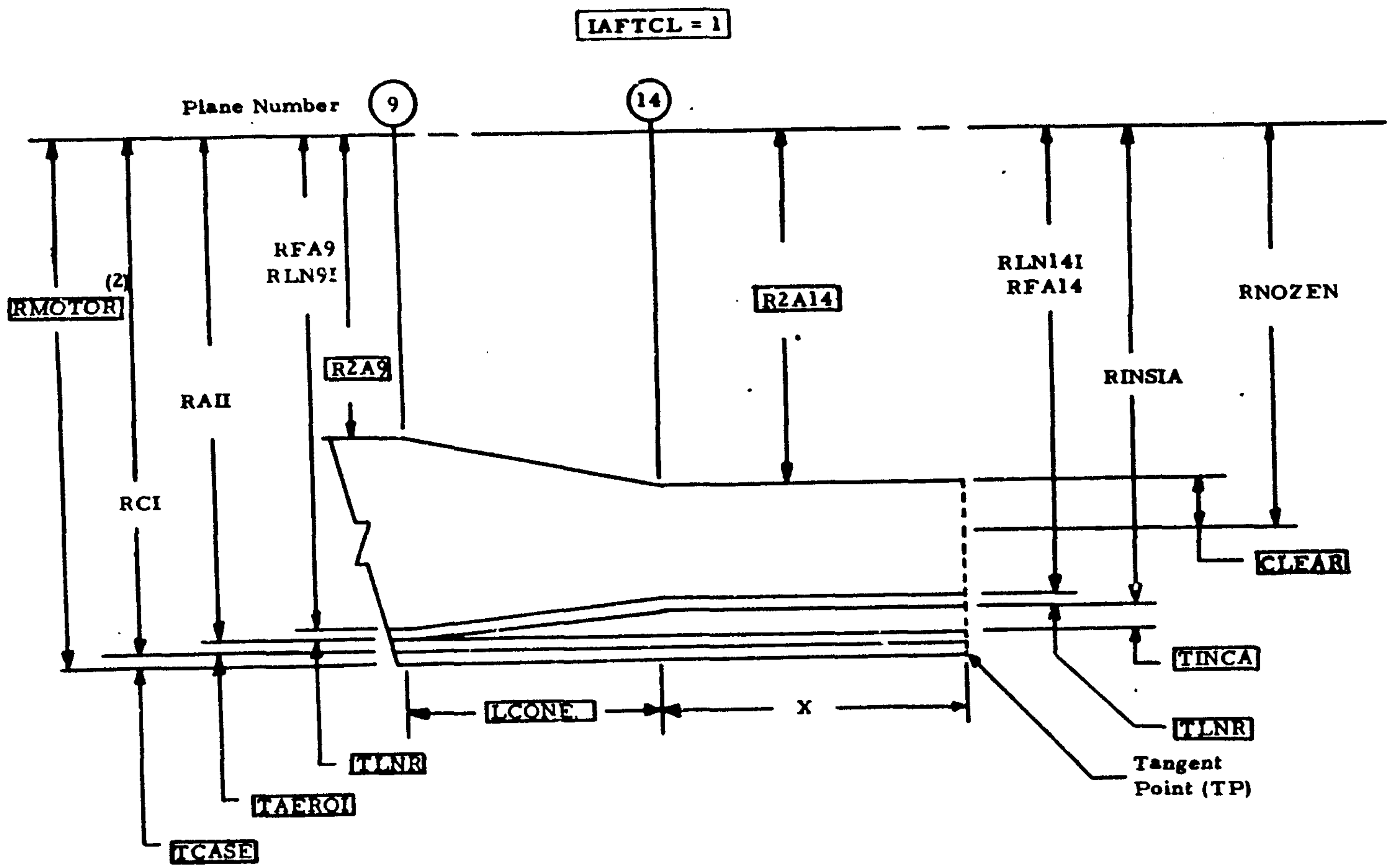
NOTES:

1. Input required for all problems.
2. Input required for all problems with forward closure Type 1.
3. Input required for all problems with aft closure Type 1.
4. Logical command to specify parameters that may be adjusted during optimization search. T = parameter will be maintained constant at input value; F = parameter will not be maintained at input value, but will be adjusted.



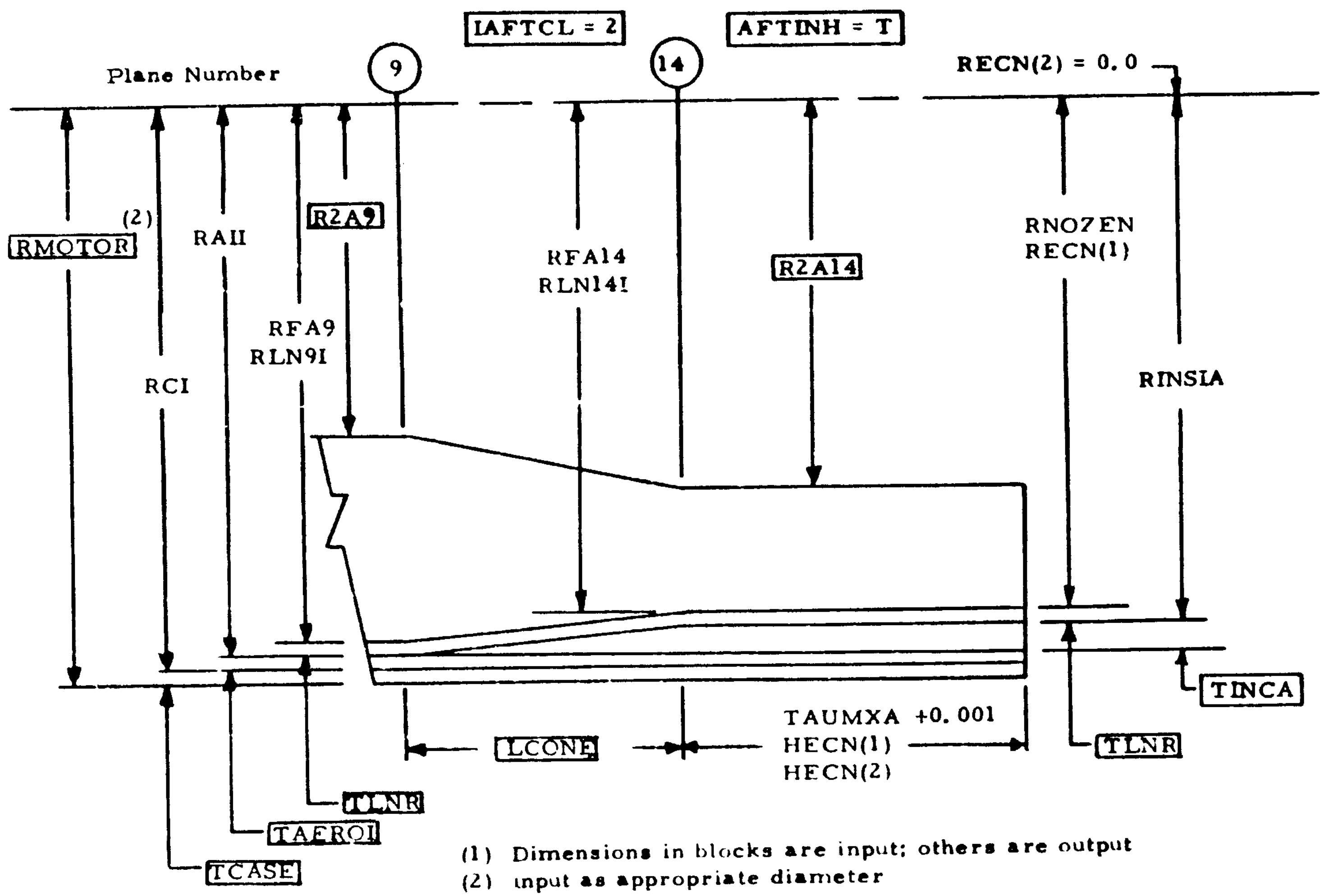
(1) Dimension shown in blocks are input; others are output
(2) Input as appropriate diameter

Figure 40. Nomenclature for Head-End of Grain Type 4



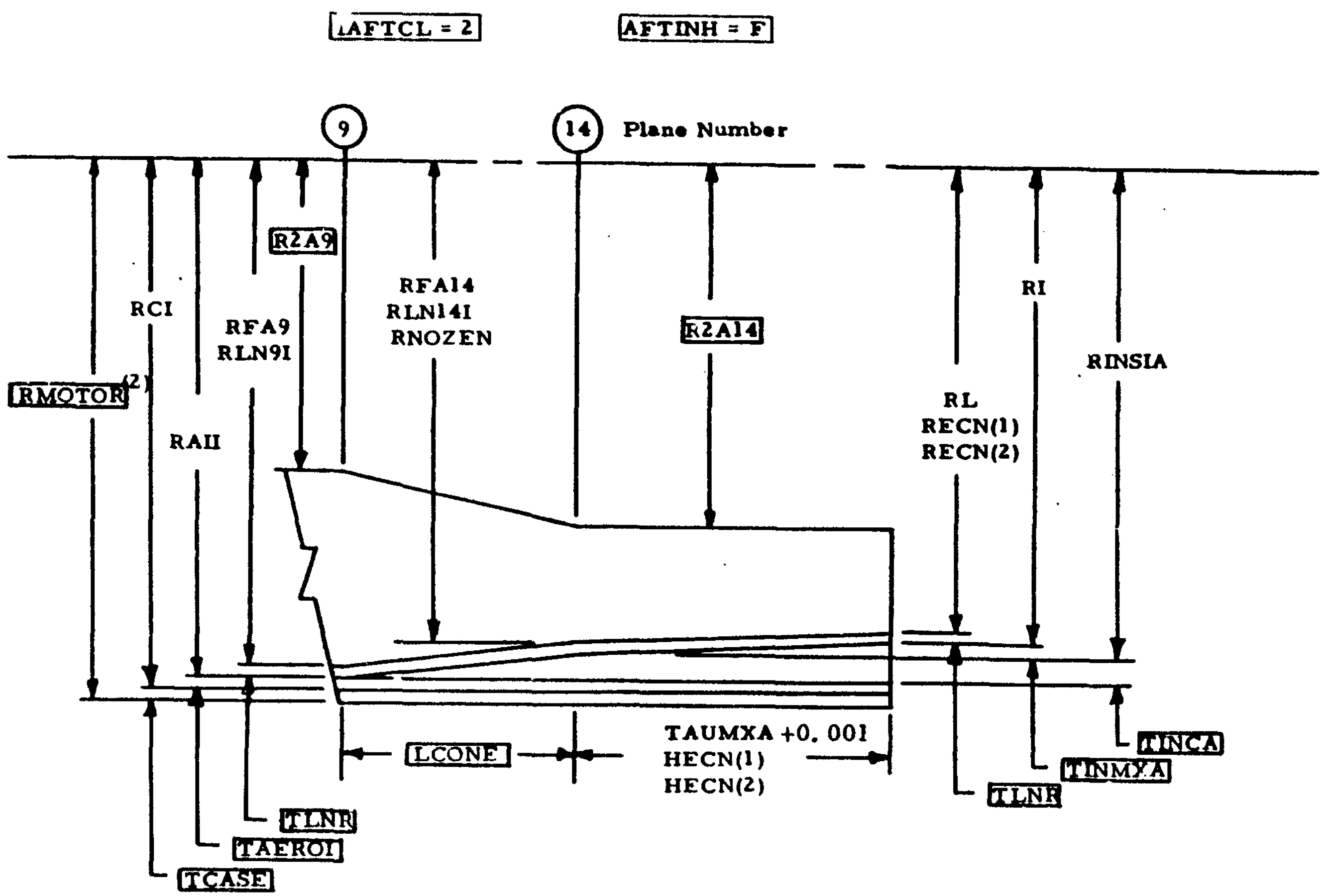
(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter
(3) X = (HECN(1)-X1A) if RFA14 < B5A, or is X = HECN(1) if RFA14 ≥ B5A

Figure 41. Nomenclature for Aft End of Grain Type 4, Aft Closure Type 1



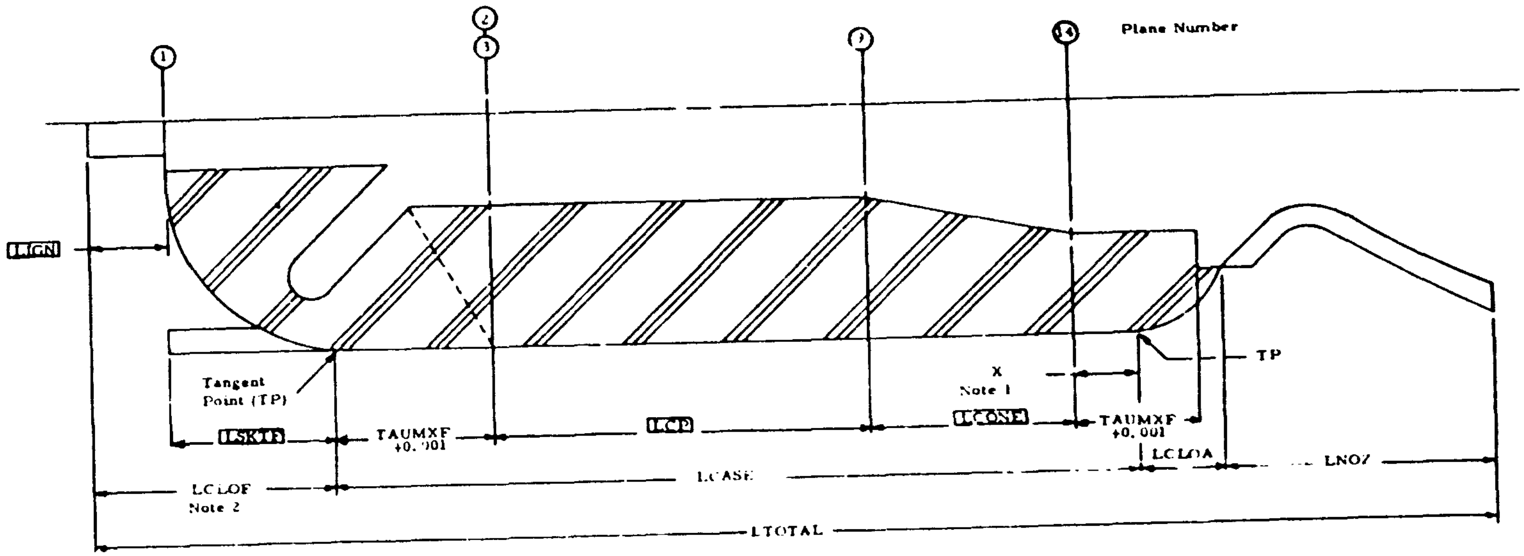
(1) Dimensions in blocks are input; others are output
(2) input as appropriate diameter

Figure 42. Nomenclature for Aft End of Grain Type 4, Aft Closure Type 2 (Inhibited)



(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter

Figure 43. Nomenclature for Aft End of Grain Types 4 and 5, Aft Closure Type 2 (Not Inhibited)



(1) X = (HECN(1) - XIA) if RFA14 < BSA; X = HECN (1) if RFA14 ≥ BSA
(2) LSKTF used to calculate LTOTAL if LSKTF > LCLOF
(3) Dimensions shown in blocks are input; others are output

Figure 44. Nomenclature for Grain Type 4 with Aft Closure Type 1

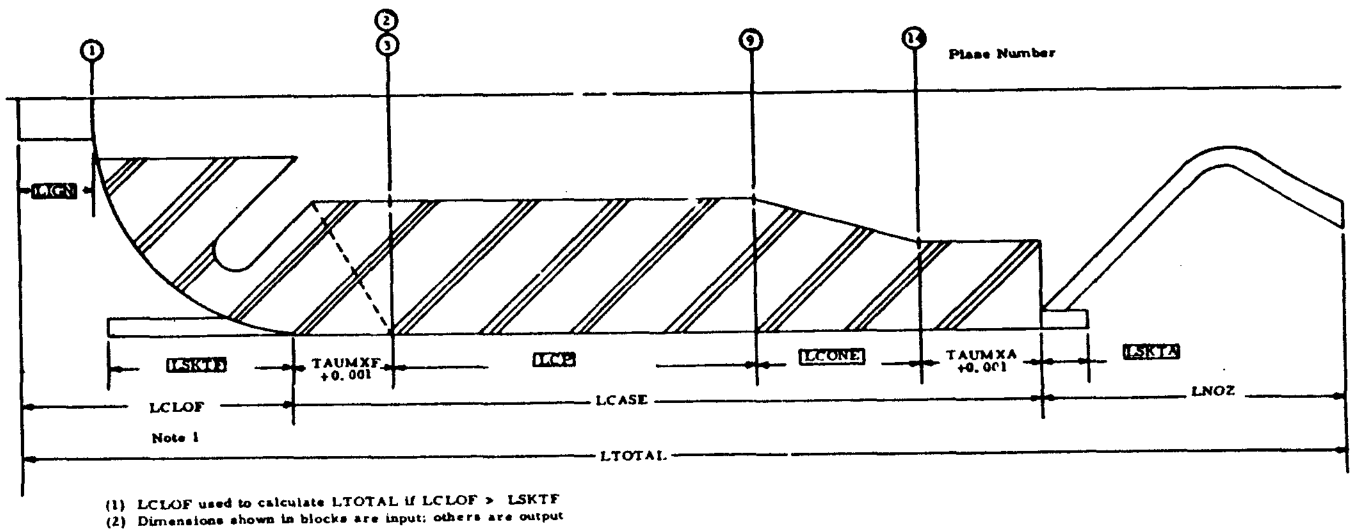


Figure 45. Nomenclature for Grain Type 4 with Aft Closure Type 2

TABLE 11

OUTPUT OF GRAIN DIMENSION SETUP

GRAIN TYPE 4 - CONOCYL

Parameter Name	Definition and Units
B5A	See Figure 10.
B5F	See Figure 6.
HECN(I)	Length (in) measured aft from Plane 14 to describe outside propellant surface in aft closure (i = 1,.... 5).
LCASE	Length (in) of cylindrical portion of case.
L3T1	Length (in) from Plane 1 to Planes 2/3.
L9T3	Length (in) from Plane 3 to Plane 9.
L14T3	Length (in) from Plane 3 to Plane 14.
OBJLH	Penalty for length of forward propellant segment so short that slot contacts forward closure.
OBJR2	Penalty for (RTIP-R1) $<$ R2A3.
OBJTIP	Penalty for (RTIP-R1) $<$ RIGN.
OBJT2	Penalty for port radius at Plane 2 (R2A2) greater than propellant outside radius (RFA1) minus slot fillet radius (R1).
OBJT3	Penalty for port radius at Plane 1 (R2A1) less than minimum allowed port radius (RIGN).
OBJT5	Penalty for web fraction at Plane 5 (WEBFR) greater than input allowable maximum (WFLIM)
OBJT7	Penalty for port radius at Plane 14 (R2A14) greater than propellant radius (RFA14).
OBJT8	Penalty for port radius at Plane 14 (R2A14) less than port radius at Plane 9 (R2A9).
OBJT10	Penalty for length of CP portion of grain less than zero.
OBJT11	Penalty for length of aft coned portion of grain less than zero.
OR2T11	Penalty for port radius at Plane 14 (R2A14) plus CLEAR greater than propellant radius (RFA14).
OBZED1	Penalty for ZED $>$ 90 deg.
OBZED2	Penalty for ZED $<$ -45 deg.

Table 11

OUTPUT OF GRAIN DIMENSION SETUP - TYPE 4 GRAIN (contd.)

Parameter Name	Definition and Units
RAII	See Figure 40
RCI	See Figure 40
RECN(I)	Radii (in) describing outside propellant surface in aft closure (I = 1.... 5).
RFA3-RFA14	Fuel radius (in) at input planes.
RINSIA	See Figure 41
RLN9I	See Figure 41
RLN14I	See Figure 41
RNOZEN	Radius (in) at aft end of case which is made compatible with the nozzle entrance radius (RN1).
R2A3-R2A14	Port radius (in) at input planes.
TAUMXA	Maximum distance burned (in) at Plane 14.
TAUMXF	Distance (in) from forward closure-case tangent point to aftmost point of exposure on case wall.
WAEROI	Weight (lbm) of aerodynamic heating insulation.
WCASCY	Weight (lbm) of cylindrical section of case.
WEBFR	Web fraction (RFA3-R2A3)/RFA3).
WINA	Weight (lbm) of insulation in aft closure.
WINF	Weight (lbm) of insulation in forward closure.
WINAFT	Weight (lbm) of insulation in cylindrical section of case aft of Plane 14.
WINCON	Weight (lbm) of insulation under aft coned portion of grain between Planes 9 and 14.
WINSCY	Weight (lbm) of insulation in cylindrical section of case (WINFWD + WINAFT + WAEROI + WINCON).
WINFWD	Weight (lbm) of insulation in cylindrical section of case forward of Plane 2/3.
WLNAFT	Weight (lbm) of liner in cylindrical section of case aft of Plane 14.

Table 11

OUTPUT OF GRAIN DIMENSION SETUP - TYPE 4 GRAIN (contd.)

Parameter Name	Definition and Units
WLNCON	Weight (lbm) of liner under aft coned portion of grain between Planes 9 and 14.
WLNFWD	Weight (lbm) of liner in cylindrical section of case forward of Plane 2/3.
WLNRA	Weight (lbm) of liner in aft closure.
WLNRF	Weight (lbm) of liner in forward closure.
WLNRCP	Weight (lbm) of liner under CP portion of grain.
WLNRCY	Weight (lbm) of liner in cylindrical section of case (WLNFWD + WLNAFT + WLNRCP + WLNCON).
WSKTA	Weight (lbm) of aft thrust skirt.
WSKTF	Weight (lbm) of forward thrust skirt.
WSRBA	Weight (lbm) of stress relief boot in aft closure Type 1.
X	See Figure 44.
X1A	See Figure 10.

GRAIN TYPE 5 - CP

This block of input data describes the cylindrically perforated (CP) grain configuration and the forward and aft closures. All data are contained in a single namelist GRAIN5.

The closure inputs are included in the input block for each grain type. However, the illustrations of the closures that show common parameters are included only in the grain Type 1 description.

Input data are provided to a subroutine SETUP5 that (1) confirms the geometric validity of all the grain dimensions (e.g., PATSH-adjusted lengths greater than zero, initial grain dimensions "close" properly, etc.); (2) checks dimensions against user-supplied limits (e.g., propellant web fraction less than limit, clearances between propellant and case greater than limit, etc.); (3) generates dimensions that describe propellant initial internal and external surfaces to the ballistic simulation module; (4) calculates all inert weights in the pressure vessel (except for pressure vessel closures, which is done after a design pressure is available from the ballistic simulation. The results of these analyses are given as part of this block of code output.

TABLE 12

NAMELIST/GRAIN5

INPUTS FOR TYPE 5 GRAIN BALLISTIC SIMULATION

Parameter Name	Default Value	Definition and Units
BETA2A	0.0 Note 3	Ellipse ratio (major/minor diameter) of inside surface of pressure vessel aft closure Type 1
BETA2F	0.0 Note 2	Ellipse ratio (major/minor diameter) of inside surface of pressure vessel forward closure Type 1
CLEAR	0.0	Radial clearance (in) between port radius and radius of aft closure opening for aft closure Type 1. Positive when port is smaller than opening.
DELAI	0.0	Density (lbm/cu in) of insulation to protect propellant grain against aerodynamic heating
DELCAS	0.0	Density (lbm/cu in) of pressure vessel (case cylindrical section and integral closures)
DELCLO	0.0	Density (lbm/cu in) of Type 2 forward closure
DELINS	0.0	Density (lbm/cu in) of case internal insulation
DELLNR	0.0	Density (lbm/cu in) of liner
DELSRB	0.0	Density (lbm/cu in) of stress relief boot
DMOTOR	Note 1	Outside diameter (in) of motor
LCONE	Note 1	Length (in) of aft coned portion of grain
LCONEF	Note 1	Length (in) of forward coned portion of grain
LCP	Note 1	Length (in) of cylindrically perforated (CP) portion of grain
LGAPF	0.0	Length (in) between forward face of grain and aft face of insulation on forward closures Type 2 or 3.
LIGN	0.0	Length (in) of igniter and/or safe-and-arm device that extends forward of the outside surface of the forward closure
LSKTA	0.0	Length (in) of aft thrust skirt
LSKTF	0.0	Length (in) of forward thrust skirt

Table 12

NAMELIST/GRAIN5 (contd.)

Parameter Name	Default Value	Definition and Units
RIGN	0.0	Minimum radius (in) of port to allow for igniter and for gas flow passage
R2A1	Note 1	Port radius (in) R2 at Plane 1
R2A5	Note 1	Port radius (in) R2 at Plane 5
R2A14	Note 1	Port radius (in) R2 at Plane 14
TAEROI	0.0	Thickness (in) of insulation to protect grain against aerodynamic heating
TCASE	Note 1	Thickness (in) of pressure vessel (case) cylindrical section
TFABC	0.0	Minimum allowed thickness (in) of case cylindrical section due to fabrication considerations
TINAMN	0.0	Thickness (in) of insulation in aft closure Type 1, measured at tangent point of closure and case cylindrical section
TINAMX	0.0	Thickness (in) of insulation in aft closure Type 1 measured at opening of closure (where nozzle attaches)
TINCA	0.0	Thickness (in) of insulation at Plane 14
TINCF	0.0	Thickness (in) of insulation at Plane 1
TINF	0.0	Thickness (in) of insulation on flat plate forward closures (Type 2 or Type 3)
TINFMN	0.0	Thickness (in) of insulation in forward closure Type 1, measured at tangent point of closure and case cylindrical section
TINFMX	0.0	Thickness (in) of insulation in forward closure Type 1, measured at RIGN radius
TINMXA	0.0	Thickness (in) of insulation at aft end of grain with aft closure Type 2 and when aft propellant face is not inhibited (AFTINH = F)
TINMXF	0.0	Thickness (in) of insulation at forward end of grain with forward closure Type 2 or Type 3 and when forward propellant face is not inhibited (FWDINH = F)

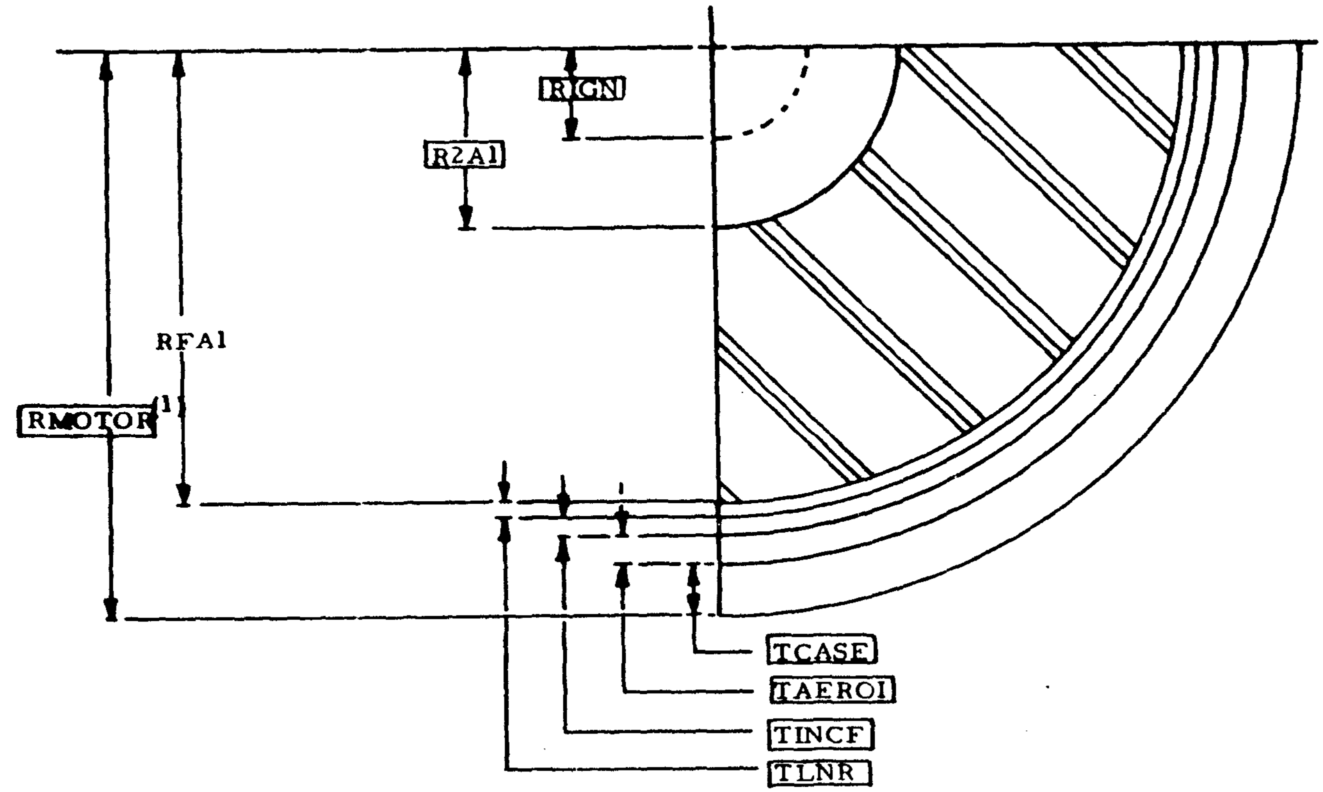
Table 12

NAMELIST/GRAIN5 (contd.)

Parameter Name	Default Value	Definition and Units
TLNR	0.0	Thickness (in) of liner, constant over entire interior surface
TSKTA	0.0	Thickness (in) of aft thrust skirt
TSKTF	0.0	Thickness (in) of forward thrust skirt
TSRBA	0.0	Thickness (in) of stress relief boot in aft closure Type 1, measured at aft case opening
TSRBF	0.0	Thickness (in) of stress relief boot in forward closure Type 1, measured at RIGN radius
WFLIM	1.0	Maximum allowed web fraction at Plane 5
FDMTR	T	Search control for motor outside diameter (DMOTOR). See Note 4.
FLCONE	T	Search control for length of aft coned portion of propellant grain (LCONE). See Note 4.
FLCONF	T	Search control for length of forward coned portion of propellant grain (LCONEF). See Note 4.
FLCP	T	Search control for length of cylindrically perforated (CP) portion of propellant grain (LCP). See Note 4.
FR2A1	T	Search control for port radius R2 at Plane 1. See Note 4.
FR2A5	T	Search control for port radius R2 at Plane 5. See Note 4.
FR2A14	T	Search control for port radius R2 at Plane 14. See Note 4.
FTCASE	T	Search control for case wall thickness in cylindrical section (TCASE). See Note 4.

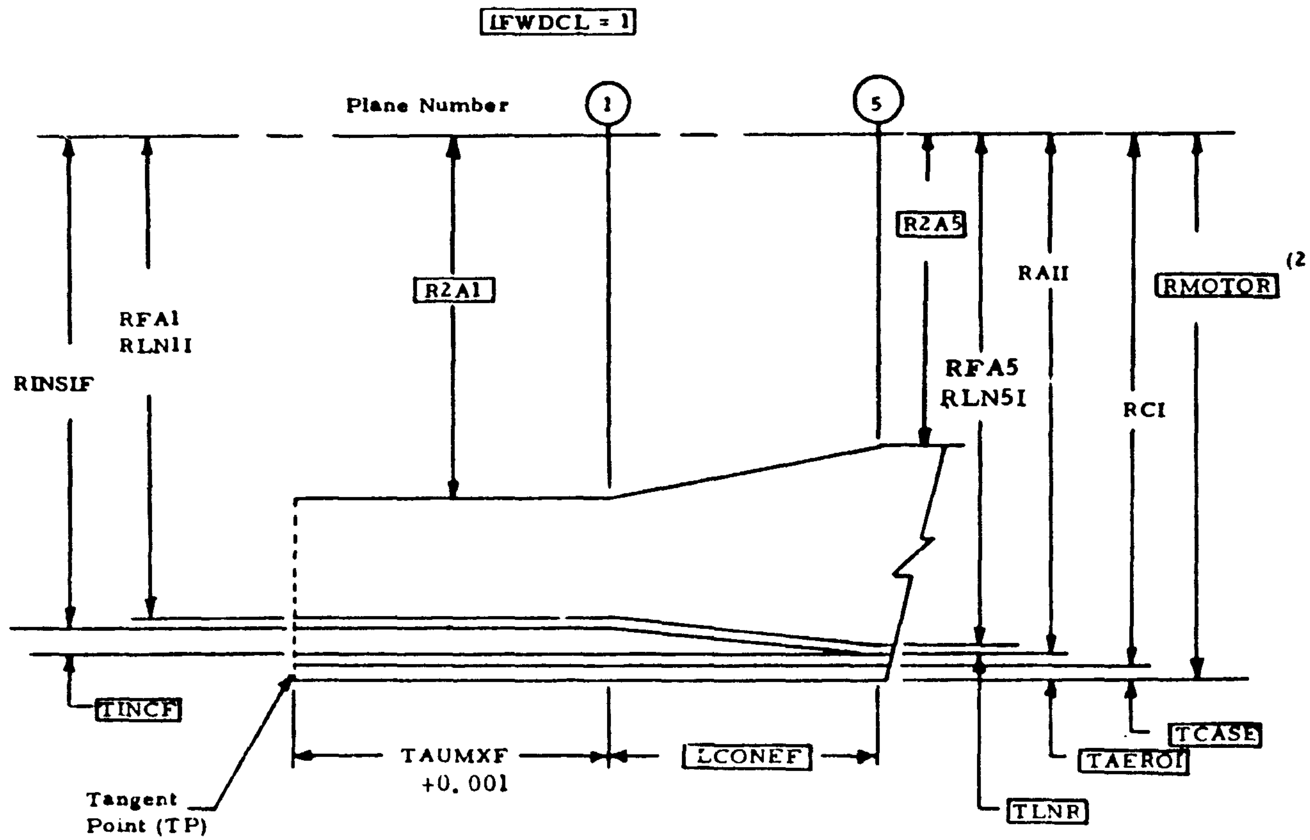
NOTES:

1. Input required for all problems.
2. Input required for all problems with forward closure Type 1.
3. Input required for all problems with aft closure Type 1.
4. Logical command to specify parameters that may be adjusted during optimization search. T = parameter will be maintained constant at input value; F = parameter will not be maintained at input value, but will be adjusted.



NOTES: (1) Input as diameter DMOTOR
(2) Dimensions shown in blocks are input; others are output.

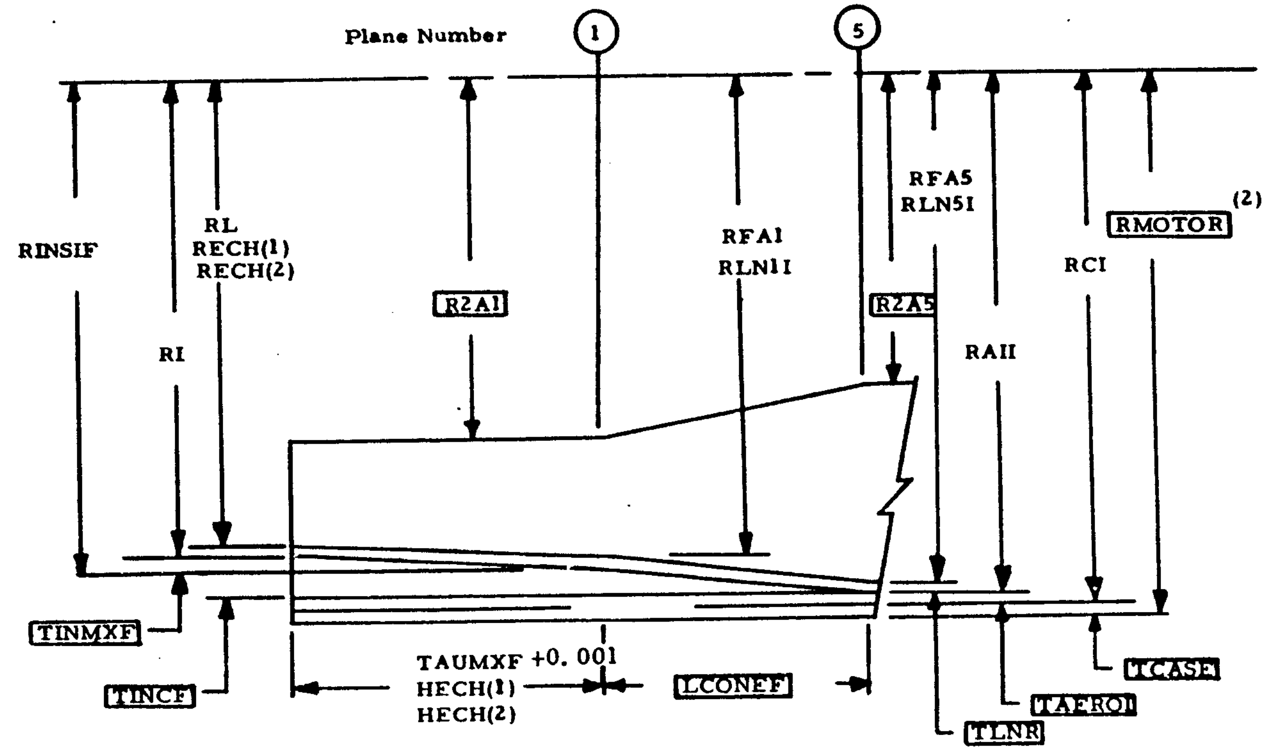
Figure 46. Inputs for Type 5 (CP) Grain (Cross-Section Shown at Plane 1)



(1) Dimensions in blocks are input; others are output
(2) Input as appropriate diameter

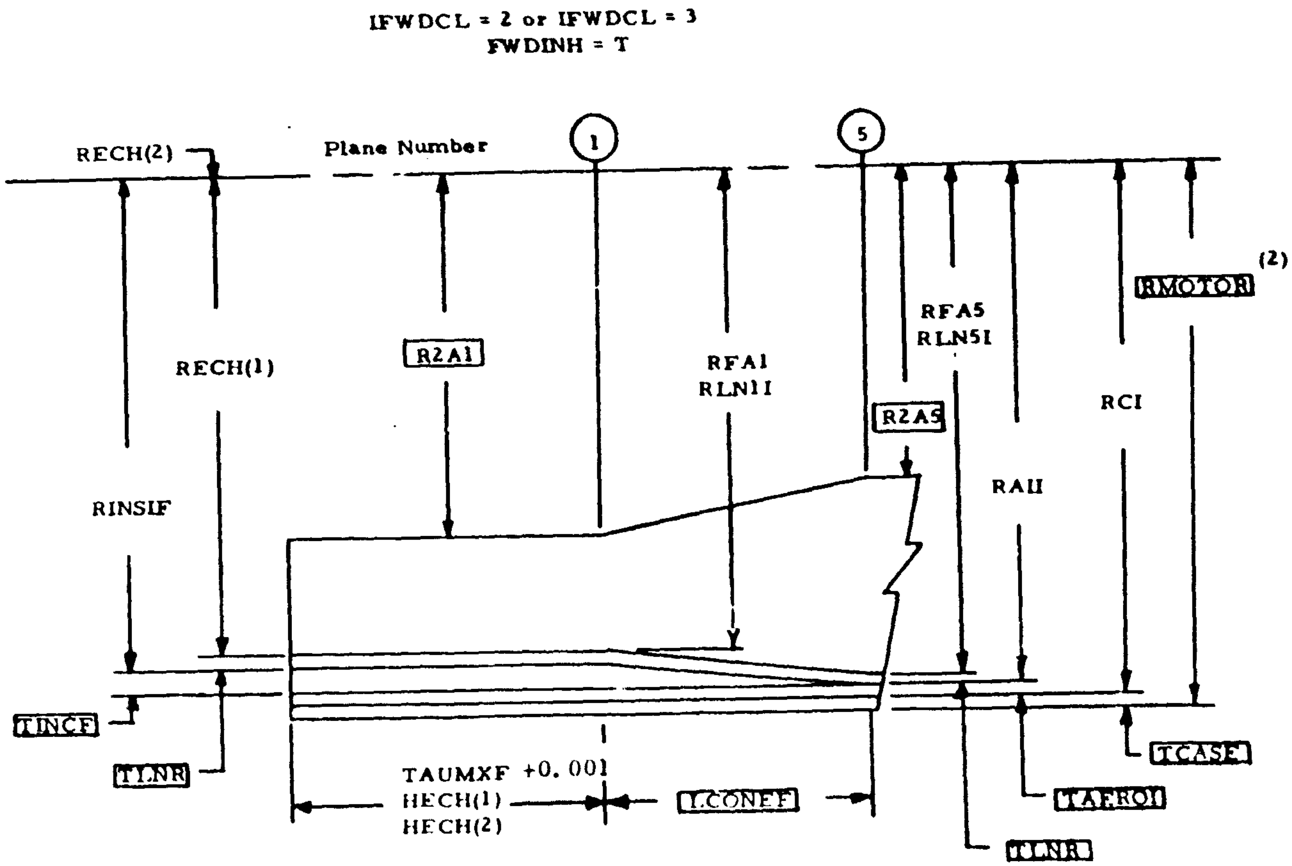
Figure 47. Nomenclature For Forward End of Grain Type 5, Forward Closure Type 1

IFWDCL = 2 or IFWDCL = 3; FWDINH = F



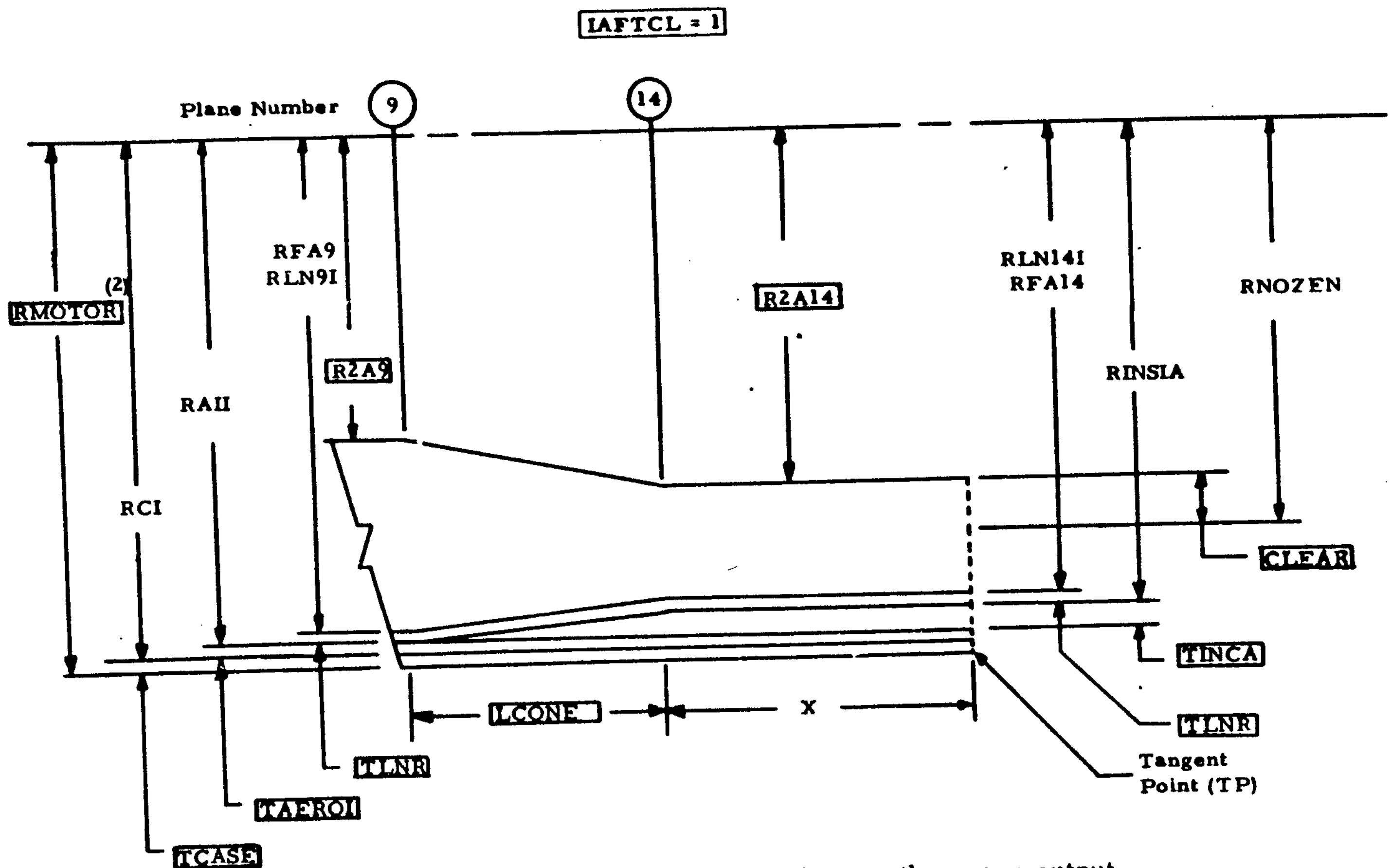
(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter

Figure 48. Nomenclature For Forward End of Grain Type 5, Forward Closure Type 2 or Type 3 (Inhibited)



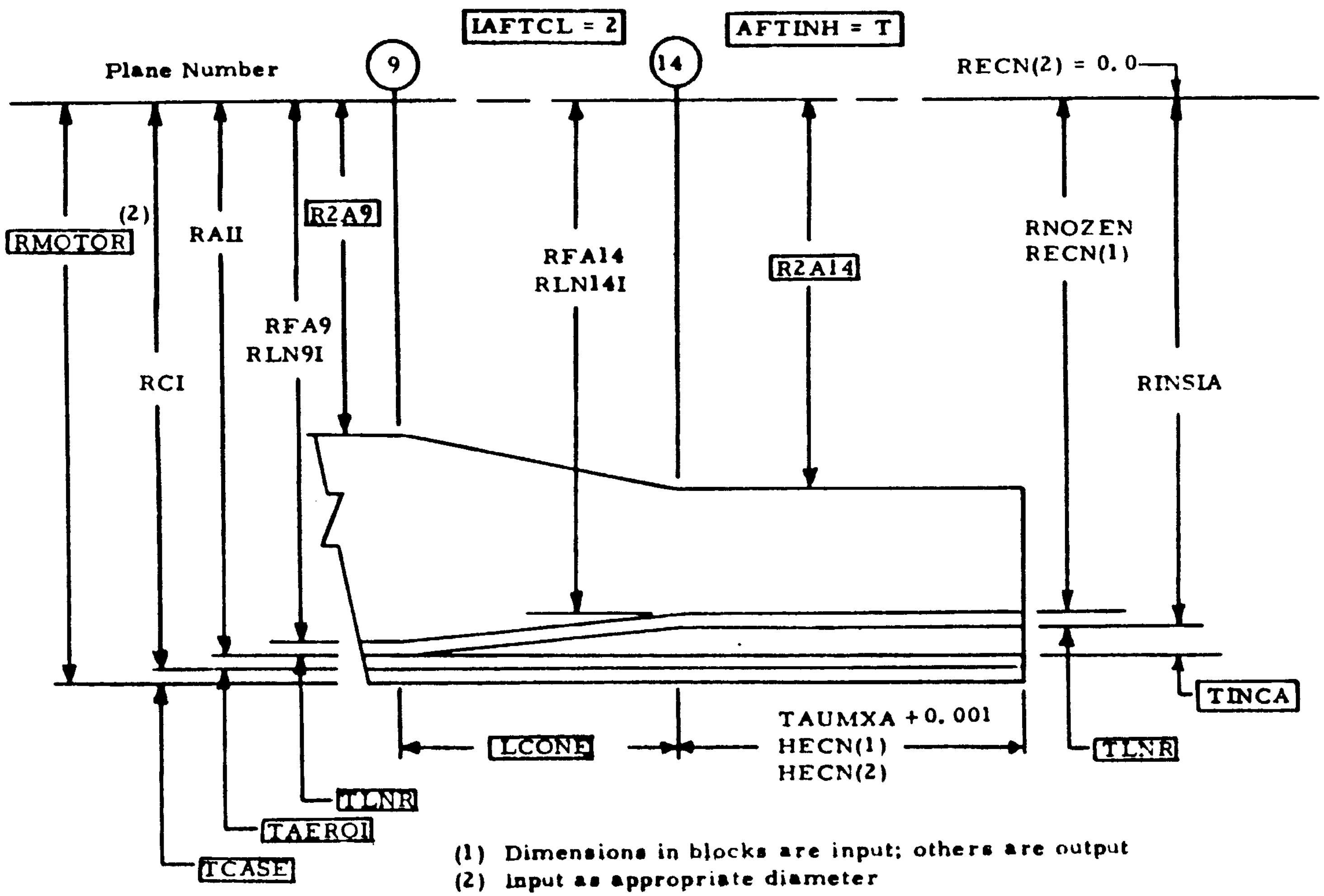
(1) . .mensions in blocks are input; others are output
(2) Input as appropriate diameter

Figure 49. Nomenclature For Forward End of Grain Type 5. Forward Closure Type 2 or 3 (Inhibited)



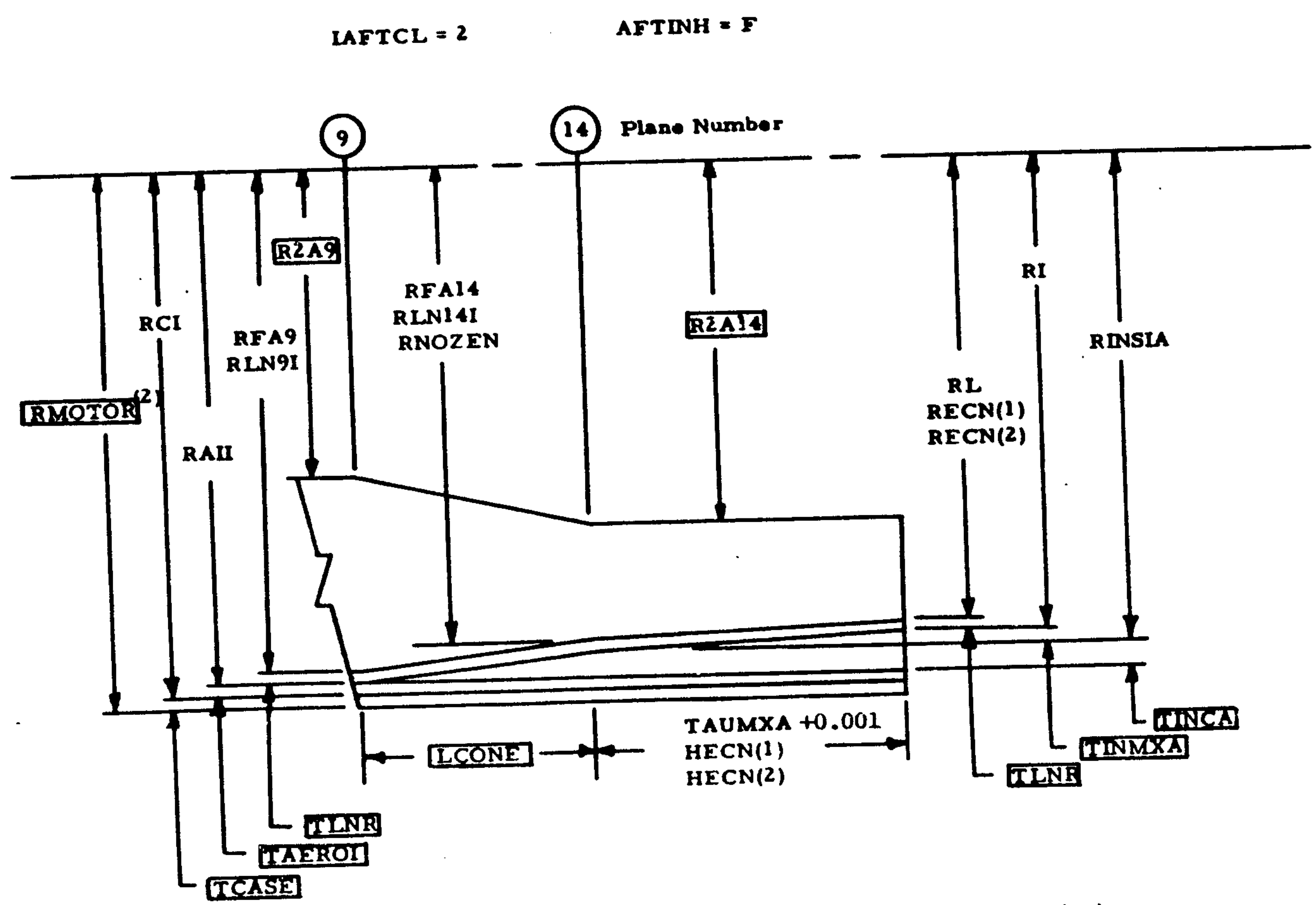
(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter
(3) X = (HECN(1)-X1A) if RFA14< B5A, or X = HECN(1) if RFA14 ≥ B5A

Figure 50. Nomenclature for Aft End of Grain Type 5, Aft Closure Type 1



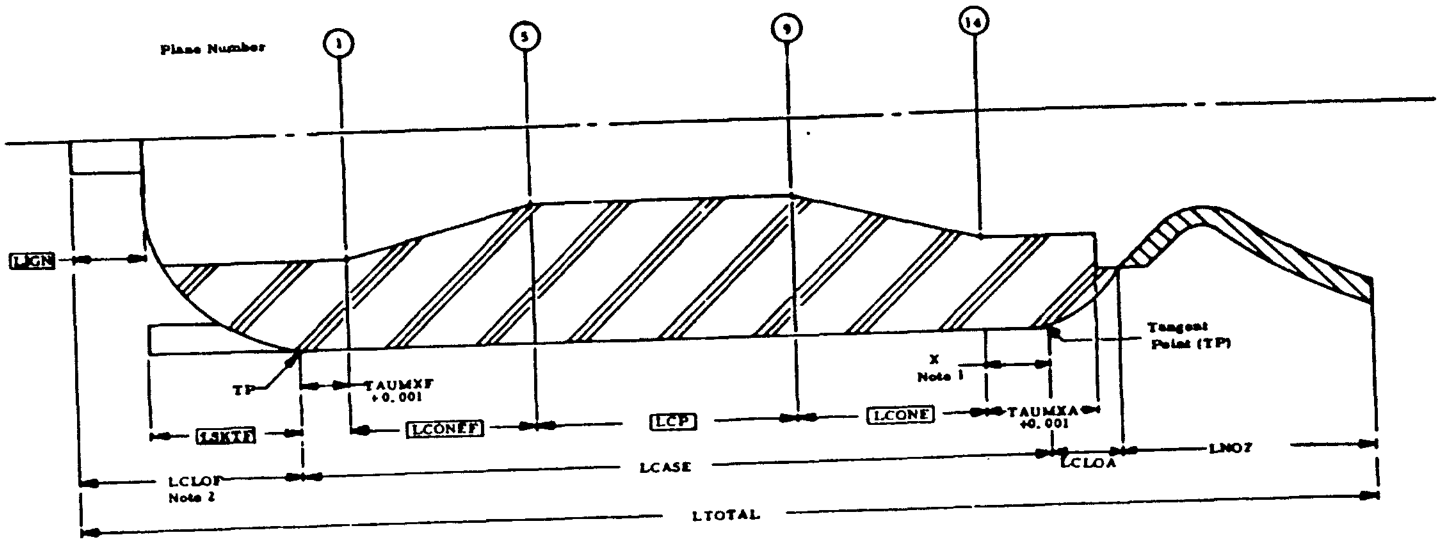
(1) Dimensions in blocks are input; others are output
(2) Input as appropriate diameter

Figure 51. Nomenclature for Aft End of Grain Type 5, Aft Closure Type 2 (Inhibited)



(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameter

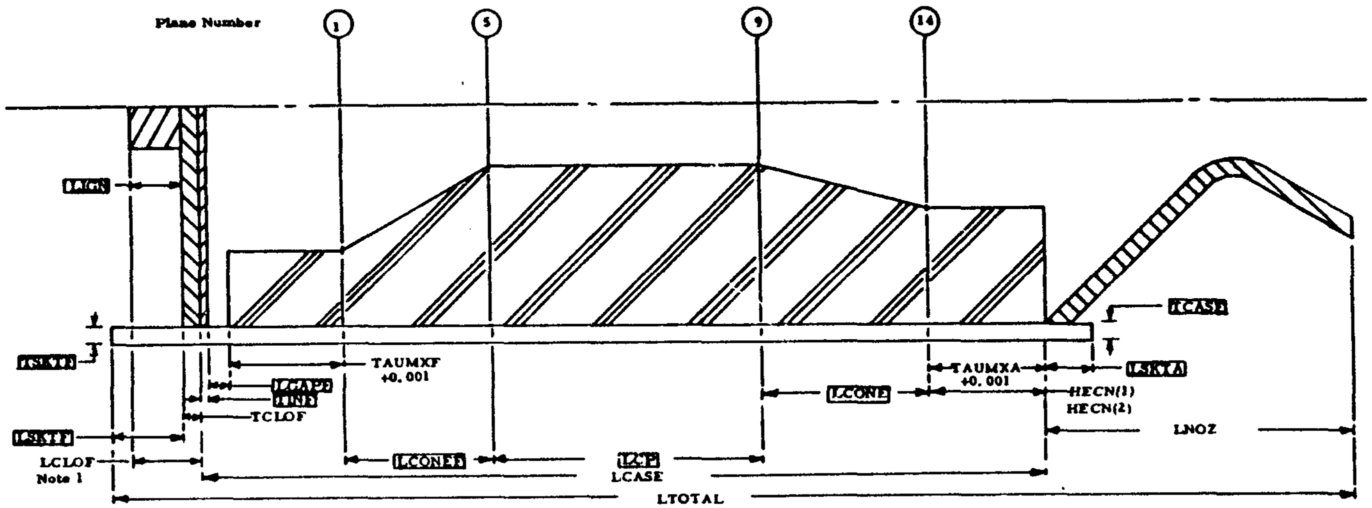
Figure 52. Nomenclature for Aft End of Grain Type 5, Aft Closure Type 2 (Not Inhibited)



NOTES

(1) For Aft Closure Type 1, this dimension is X = (HECN(1)-X1A) if RFA14 < BSA, or X = HECN(1) if RFA14≥BSA
(2) LSFTF used to calculate LTOTAL if LSKTF > LCLOF
(3) Dimensions shown in blocks are input; others are output

Figure 53. Nomenclatu·e For Grain Type 5 With Aft Closure Type 1 and Forward Closure Type 1



NOTE

(1) LCLOF used to calculate LTOTAL if LCLOF > LSKTF
(2) Dimensions shown in blocks are input; others are output

Figure 54. Nomenclature For Grain Type 5 With Aft Closure Type 2 and Forward Closure Type 2 or 3

TABLE 13

OUTPUT OF GRAIN DIMENSION SETUP

GRAIN TYPE 5 - CP

Parameter Name	Definition and Units
ALPHA1-14	Equal to zero for CP grain
B5A	See Figure 10.
B5F	See Figure 6.
HECH(I)	Length (in) measured forward from Plane 1 to describe outside propellant surface in forward closure (I=1, . . . , 5)
HECN(I)	Length (in) measured aft from Plane 14 to describe outside propellant surface in aft closure (i=1, . . . , 5)
LCASE	Length (in) of cylindrical portion of case
L5T1-L14T1	Length (in) from Plane 1 to downstream input planes
OBJT2	Penalty for port radius at Plane 1 (R2A1) greater than propellant outside radius (RFA1)
OBJT3	Penalty for port radius at Plane 1 (R2A1) less than minimum allowed port radius (RIGN)
OBJT4	Penalty for port radius at Plane 5 (R2A5) greater than propellant outside radius (RFA5)
OBJT5	Penalty for web fraction at Plane 5 (WEBFR) greater than input allowable maximum (WFLIM)
OBJT6	Penalty for port radius at Plane 1 (R2A1) less than port radius at Plane 5 (R2A5)
OBJT7	Penalty for port radius at Plane 14 (R2A14) greater than propellant radius (RFA14)
OBJT8	Penalty for port radius at Plane 14 (R2A14) less than port radius at Plane 9 (R2A9)
OBJT9	Penalty for length of forward coned portion of grain (LCONEF) less than zero
OBJT10	Penalty for length of CP portion of grain (LCP) less than zero
OBJT11	Penalty for length of aft coned portion of grain (LCONE) less than zero
OR2T11	Penalty for port radius at Plane 14 (R2A14) plus CLEAR greater than propellant radius (RFA14)

Table 13

OUTPUT OF GRAIN DIMENSION SETUP - TYPE 5 GRAIN (contd.)

Parameter Name	Definition and Units
RAII	See Figure 47.
RCI	See Figure 47.
RECH(I)	Radii (in) describing outside propellant surface in forward closure (I=1,...,5)
RECN(I)	Radii (in) describing outside propellant surface in aft closure (I=1,...,5)
RFA1-RFA14	Fuel radius (in) at input planes
RINSIF	See Figure 47
RINSIA	See Figure 50
RLN1I	See Figure 47
RLN5I	See Figure 47
RLN9I	See Figure 50
RLN14I	See Figure 50
RNOZEN	Radius (in) at aft end of case which is made compatible with the nozzle entrance radius (RN1)
R2A1-R2A14	Port radius (in) at input planes
R3A1-R3A14	Equal to zero for CP grain
R4A1-R4A14	Equal to zero for CP grain
R5A1-R5A14	Equal to R2A1-14 for CP grain
TAUMXA	Maximum distance burned (in) at Plane 14 (PFA14-R2A14)
TAUMXF	Maximum distance burned (in) at Plane 1 (RFA1-R2A1)
WAEROI	Weight (lbm) of aerodynamic heating insulation
WCASCY	Weight (lbm) of cylindrical section of case
WEBFR	Web fraction (RFA5-R2A5)/RFA5
WINA	Weight (lbm) of insulation in aft closure
WINF	Weight (lbm) of insulation in forward closure
WINSA	Weight (lbm) of insulation in cylindrical section of case aft of Plane 14
WINSCY	Weight (lbm) of insulation in cylindrical section of case (WINSF + WINSA + WAEROI)

Table 13

OUTPUT OF GRAIN DIMENSION SETUP - TYPE 5 GRAIN (contd.)

Parameter Name	Definition and Units
WINSF	Weight (lbm) of insulation in cylindrical section of case forward of Plane 1
WLNAFT	Weight (lbm) of liner in cylindrical section of case aft of Plane 14
WLNFWD	Weight (lbm) of liner in cylindrical section of case forward of Plane 1
WLNRA	Weight (lbm) of liner in aft closure
WLNRF	Weight (lbm) of liner in forward closure
WLNRCP	Weight (lbm) of liner under CP portion of grain
WLNRCY	Weight (lbm) of liner in cylindrical section of case (WLNFWD + WLNAFT + WLNRCP)
WSKTA	Weight (lbm) of aft thrust skirt
WSKTF	Weight (lbm) of forward thrust skirt
WSRBA	Weight (lbm) of stress relief boot in aft closure Type 1
WSRBF	Weight (lbm) of stress relief boot in forward closure Type 1
X	See Figure 53.
X1A	See Figure 10.

NOZZLE VERIFICATION

This collection of input data describes the nozzle geometry, materials and heat transfer characteristics. Data are contained in three separate blocks, or namelists: NOZGEO, NOZMTL, NOZHT.

A subroutine, NOZINP, (1) performs the dimensional verification checks (e.g., exit diameter greater than throat diameter); (2) calculates the degree of incompatibility (if any) between the nozzle entrance radius RN1 and the corresponding radius on the case (RNOZEN).

Output of this block of the code are penalties generated when adjustments must be made to the incoming dimensions and the final throat and exit radii that will be used in the ballistic simulation.

The nozzle thermal and structural analyses are not performed until after the ballistic simulation, so those results are given later in this manual.

TABLE 14

NAMELIST/NOZGEO

INPUTS FOR NOZZLE GEOMETRY

Parameter Name	Default Value	Definition and Units
ALFA	Note 1 & 2	Slope of nozzle internal surface measured from motor centerline (deg) at aft most point on throat circular portion. (See Figure 55).
ALFAEN	Note 1	Nozzle entrance angle (deg) measured from centerline.
ALFAEX	15.0 Note 1	Nozzle divergence half-angle at exit (deg).
AR1	Note 1	For Nozzle Types 1 and 2: Area ratio in entrance of nozzle at which insulation material changes from material No. 1 to material No. 2 (area at change/area of throat). For Nozzle Types 5 and 6: Ratio of flow area of blast tube to throat area. Does not apply to nozzle Types 3 and 4.
AR2	Note 1	For nozzle Types 1, 2 and 6: Area ratio in exit of nozzle at which insulation material changes from material No. 2 to material No. 3 (area at change/throat area). For Nozzle Type 5: Area ratio at nozzle exit. Does not apply to nozzle Types 3 or 4.
DBTO4	100.	Maximum allowable outside diameter (in) of blast tube for Nozzle Type 4. See Note 3.
DBTO5	100.	Maximum allowable outside diameter (in) of blast tube for nozzle Type 5. See Note 3.
DBTO6	100.	Maximum allowable outside diameter (in) of blast tube for nozzle Type 6. See Note 3.
DE	Note 1	Inside diameter of nozzle exit (in).
DTI	Note 1	Initial diameter of nozzle throat (in).
DX	1.0	Incremental length step size (in) along nozzle centerline at which analyses are performed.
FALFAX	T	Search control for half-angle at nozzle exit (ALFAEX). See Note 4.
FDE	T	Search control for exit diameter (DE). See Note 4.

Table 14

NAMELIST/NOZGEO (contd.)

Parameter Name	Default Value	Definition and Units
FDTI	T	Search control for nozzle initial diameter (DTI). See Note 4.
LBT	100.0	Length (in) of blast tube from nozzle entrance to start of throat contraction for Nozzle Types 5 and 6.
LBT4RQ	Note 1	Required length (in) of Blast Tube (reduced diameter aft section) for Nozzle Type 4 (LBT4).
NPLAS	1	Integer to specify presence of second structural support material NPLAS = 1: Second material exists NPLAS ≠ 1: Only one material exists Applies only to Nozzle Types 1, 2 and 6. Other nozzles have only one support structure material by definition.
NTMR	1.0	Ratio of nozzle outside exit diameter (DEO) to motor outside diameter (DMOTOR) which establishes maximum allowed nozzle exit outside diameter
RATIO	1.0	Ratio of nozzle throat radius of curvature to nozzle throat radius, RTC/(DTI/2.0).
TENT	100.	Thickness (in) of entrance insulation for Nozzle Type 4, 5 and 6. Measured perpendicular to inside contour.
TFAB	0.0	Minimum thickness limit (in) due to manufacturing considerations for support structural material No. 1.
TFABP	0.0	Minimum thickness limit (in) due to manufacturing considerations for support structure material No. 2.
TSTR4	100.	Thickness (in) of support structure in blast tube for Nozzle Type 4.
TSTR3	100.	Thickness (in) of support structure for Nozzle Type 3.

Table 14

NAMELIST/NOZGEO (contd.)

Parameter Name	Default Value	Definition and Units
XSTRAN	100.	Axial distance (in) between insulation Material 2/ Material 3 transition and structural support Material 1/Material 2 transition. Default value cannot be over-riden for Nozzle Types 3, 4, 5 and 6.

NOTES:

1. Input required for all problems.
2. Input ALFA equal to ALFAEX for conical nozzle and ALFA>ALFAEX for contoured nozzle.
3. Calculated DBTO compared to this value.
4. Logical command to specify parameters that may be adjusted during optimization search. T = parameter will be maintained constant at input value; F = parameter will not be maintained constant, but will be adjusted.
5. Support structure thickness for Nozzle Type 3 is TCASE when aft closure Type 1 is specified

TABLE 15

NAMELIST/NOZMTL

INPUTS FOR NOZZLE MATERIAL CHARACTERISTICS

Parameter Name	Default Value	Definition and Units
ALFAD1	Note 1	Char layer thermal diffusivity (sq in/sec) of insulating material No. 1.
ALFAD2	Note 1, 3	Char layer thermal diffusivity (sq in/sec) of insulating material No. 2.
ALFAD3	Note 1, 3	Char layer thermal diffusivity (sq in/sec) of insulating material No. 3.
ALFAT1	Note 1	Virgin material thermal diffusivity (sq in/sec) of insulating material No. 1.
ALFAT2	Note 1, 3	Virgin material thermal diffusivity (sq in/sec) of insulating material No. 2.
ALFAT3	Note 1, 3	Virgin material thermal diffusivity (sq in/sec) of insulating material No. 3.
C11... C61	Note 1	Erosion model coefficients for insulating material No. 1.
C12,... C62	Note 1, 3	Erosion model coefficients for insulating material No. 2.
C13.... C63	Note 1, 3	Erosion model coefficients for insulating material No. 3.
CIT1	1.0	Thermal barrier factor of safety for insulating material No. 1.
CIT2	1.0	Thermal barrier factor of safety for insulating material No. 2.
CIT3	1.0	Thermal barrier factor of safety for insulating material No. 3.
EMOD	Note 1, 3	Modulus of elasticity (psi) of structural material No. 1.
EMODP	Note 1	Modulus of elasticity (psi) of structural material No. 2.
FCY	Note 1	Compressive yield strength (psi) of structural material No. 1.
FCYP	Note 1, 3	Compressive yield strength (psi) of structural material No. 2.

Table 15

NAMELIST/NOZMTL (contd.)

Parameter Name	Default Value	Definition and Units
FSTRUP	1.0	Factor of safety for structural material No. 2.
FSTRUS	1.0	Factor of safety for structural material No. 1.
FSY	Note 1	Shear yield strength (psi) of structural material No. 1.
FSYP	Note 1,3	Shear yield strength (psi) of structural material No. 2.
FTY	Note 1	Tensile yield strength (psi) of structural material No. 1.
FTYP	Note 1,3	Tensile yield strength (psi) of structural material No. 2.
RHO1	Note 1	Density (lbm/cu in) of insulating material No. 1.
RHO2	Note 1,3	Density (lbm/cu in) of insulating material No. 2.
RHO3	Note 1,3	Density (lbm/cu in) of insulating material No. 3.
RHOP	Note 1,3	Density (lbm/cu in) of structural material No. 2.
RHOS	Note 1	Density (lbm/cu in) of structural material No. 1.

NOTES:

(1) Inputs required for all problems.
(2) See Volume I for details of erosion rate model, factors of safety, etc.
(3) Inputs associated with insulating materials No. 2 and No. 3 and structural material No. 2 are required only when these materials are present.

TABLE 16

NAMELIST/NOZHT

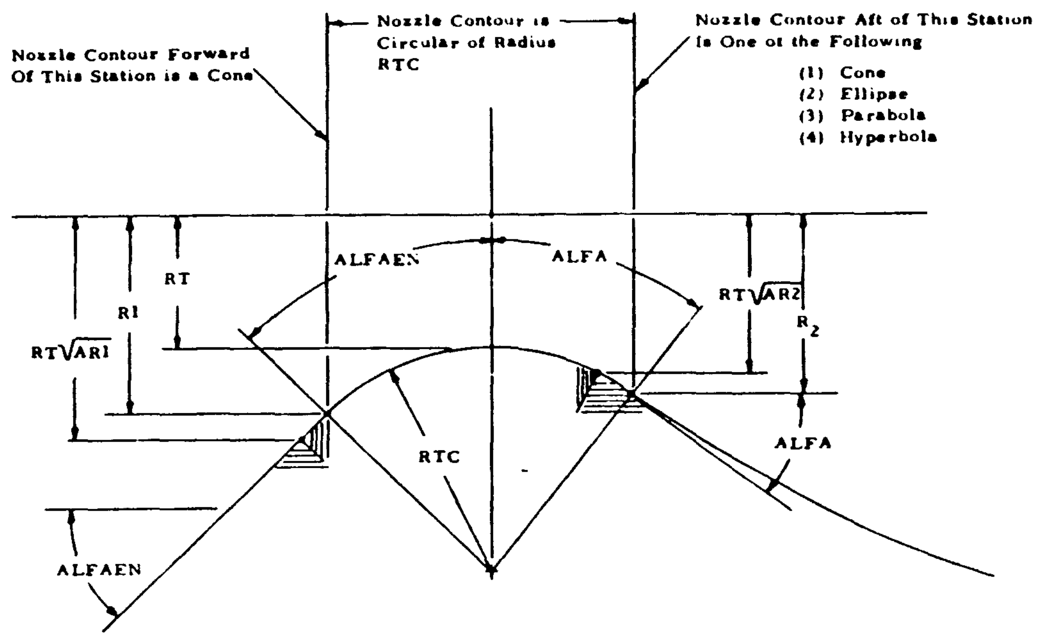
INPUTS FOR NOZZLE HEAT TRANSFER INFORMATION

Parameter Name	Default Value	Definition and Units
H1, H2, H3	Note 1, 2	Surface heat transfer coefficient (BTU/sq in-sec-°F) for insulating material No. 1, 2, and 3, respectively. See Note 2.
TALOW1	70.0	Allowable temperature (°F) for structure under insulating material No. 1.
TALOW2	70.0	Allowable temperature (°F) for structure under insulating material No. 2.
TALOW3	70.0	Allowable temperature (°F) for structure under insulating material No. 3.
TCHAR1	Note 1	Char temperature (°F) of insulating material No. 1.
TCHAR2	Note 1, 2	Char temperature (°F) of insulating material No. 2.
TCHAR3	Note 1, 2	Char temperature (°F) of insulating material No. 3.
TVAP1	Note 1	Vaporization temperature (°F) of insulating material No. 1.
TVAP2	Note 1, 2	Vaporization temperature (°F) of insulating material No. 2.
TVAP3	Note 1, 2	Vaporization temperature (°F) of insulating material No. 3.
XK1, XK2, XK3	Note 1, 2	Virgin material thermal conductivity (BTU/in-sec-°F) of insulating material No. 1, 2, and 3, respectively.
XKA, XKB, XKC	Note 1, 2	Char thermal conductivity (BTU/in-sec-°F) of insulating material No. 1, 2, and 3, respectively.

NOTES:

(1) Input required for all problems.

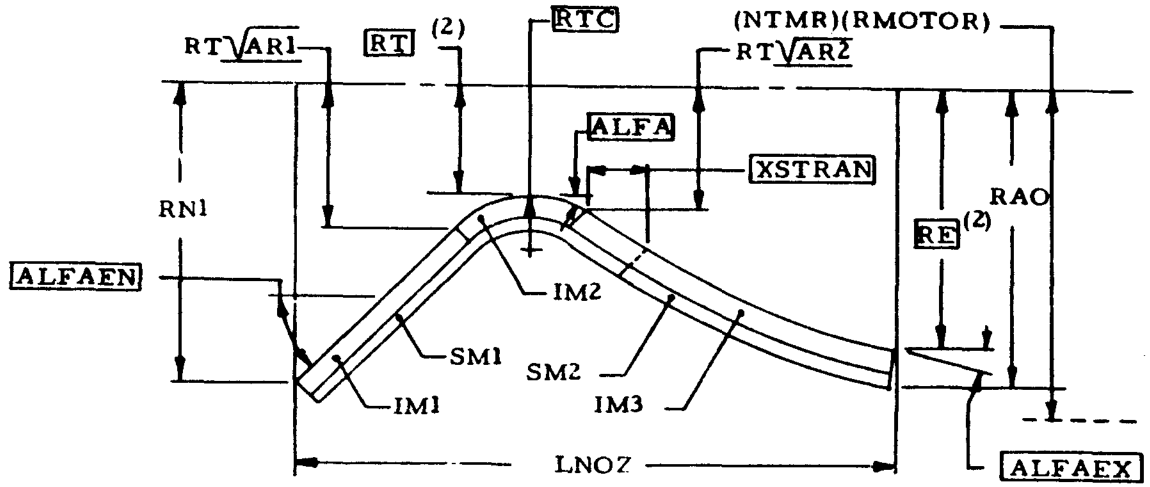
(2) Inputs associated with insulating materials No. 2 and No. 3 and with structural material No. 2 are required only when those materials are present.



(1) ALFAEN & ALFA apply to nozzle types 1, 2, 3, 4, 5, & 6
(2) AR1 & AR2 apply only to nozzle types 1, 2, 5 & 6
(3) RT$\sqrt{AR1}$ may be equal to, less than, or greater than R1
(4) RT$\sqrt{AR2}$ may be equal to, less than, or greater than R2

Figure 55. General Nozzle Dimensional Relationships

NOZZLE TYPE 1



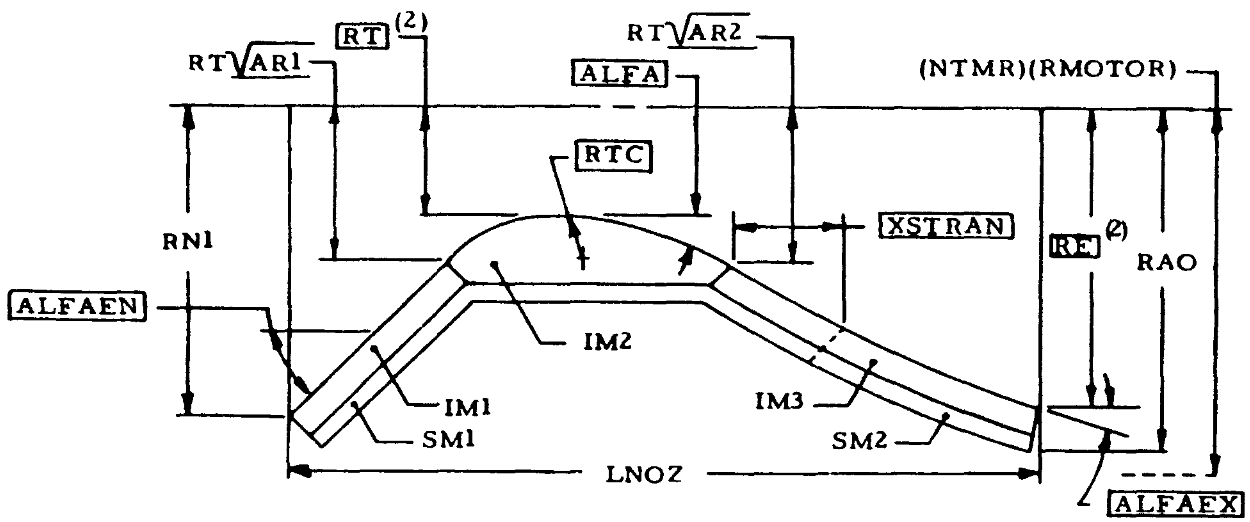
(1) Dimensions shown in blocks or underlined are input; others are output

(2) Input as appropriate diameters

(3) IM1 = Insulating Material No. 1
IM2 = Insulating Material No. 2
IM3 = Insulating Material No. 3
SM1 = Structural Material No. 1
SM2 = Structural Material No. 2

Figure 56. Dimensional Inputs for Nozzle Type 1

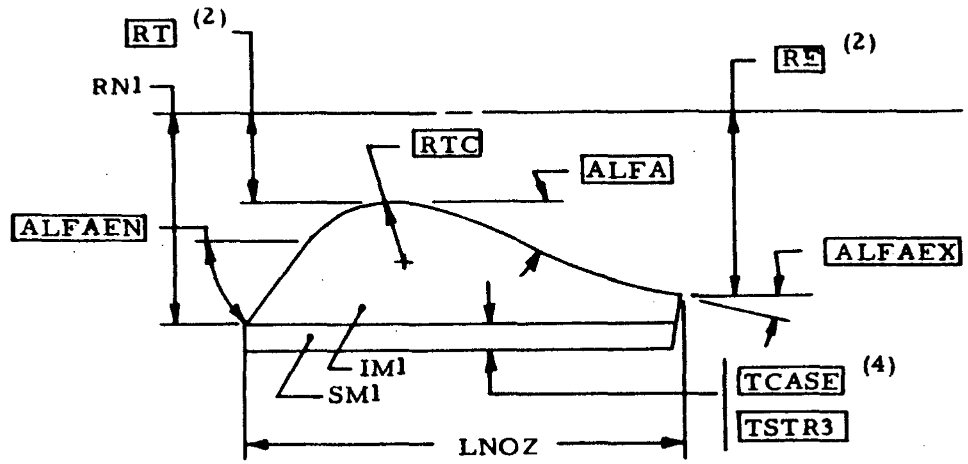
NOZZLE TYPE 2



(1) Dimensions shown in blocks or underlined are input; others are output
(2) Input as appropriate diameters
(3) IM1 = Insulating Material No. 1
IM2 = Insulating Material No. 2
IM3 = Insulating Material No. 3
SM1 = Structural Material No. 1
SM2 = Structural Material No. 2

Figure 57. Dimensional Inputs for Nozzle Type

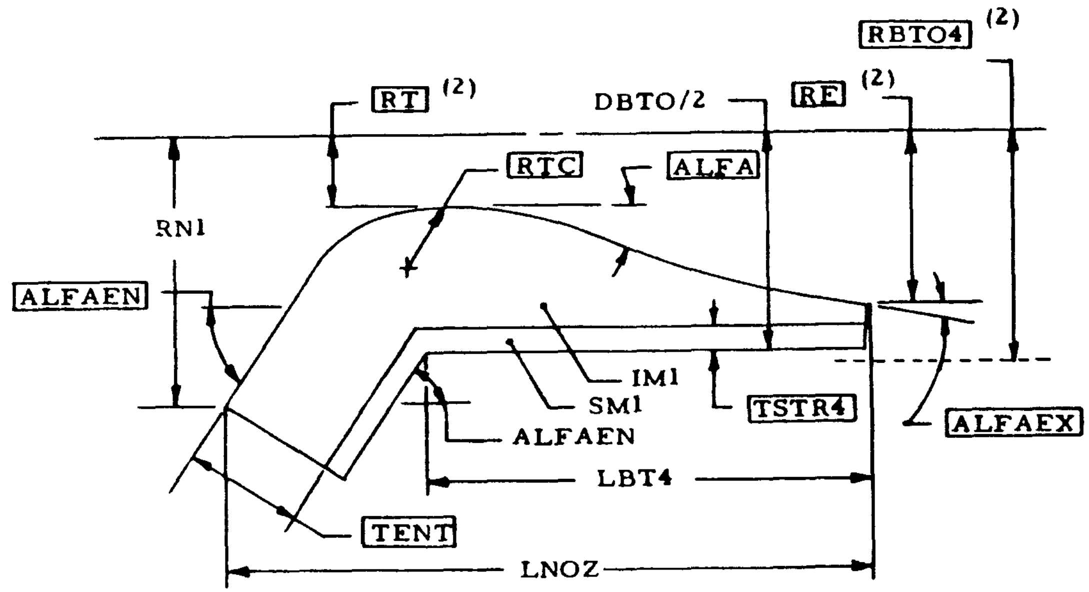
NOZZLE TYPE 3



(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameters
(3) IM1 = Insulating Material No. 1
SM1 = Structural Material No. 1
(4) TSTR3 is user-input for Aft Closure Type 1 (IAFTCL=1); if IAFTCL=2, TSTR3 is internally set to TCASE.

Figure 58. Dimensional Inputs for Nozzle Type 3

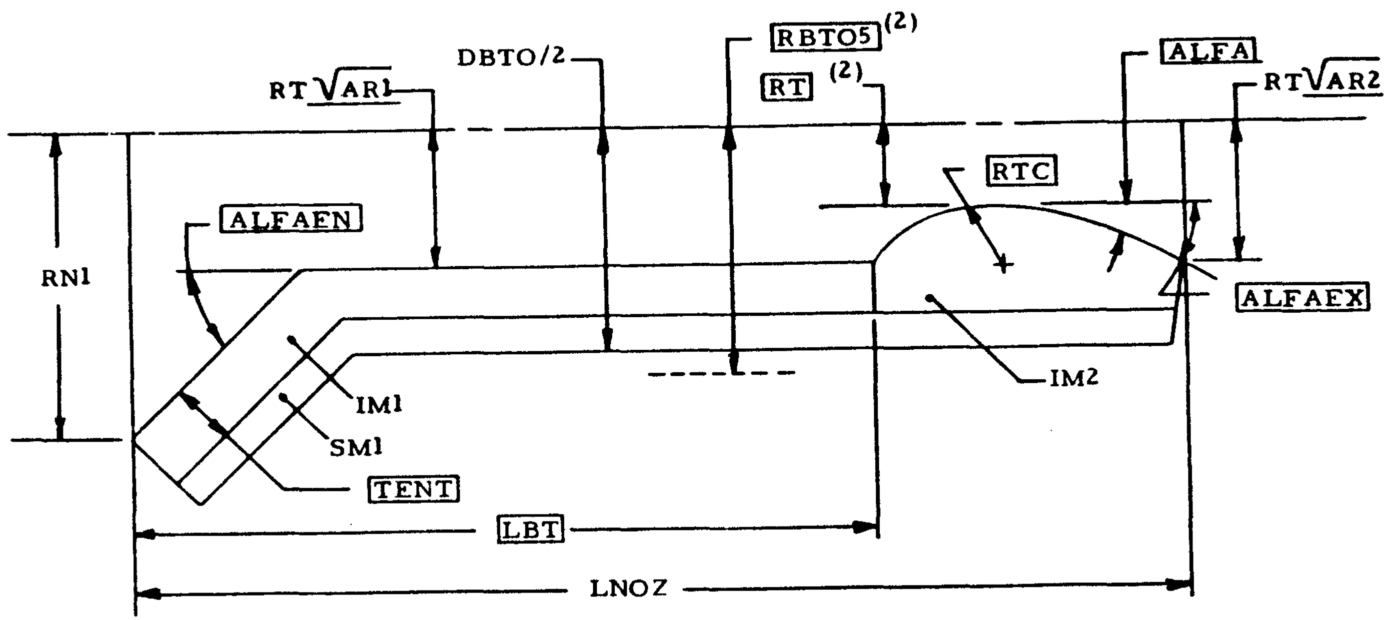
NOZZLE TYPE 4



(1) Dimensions shown in blocks are input; others are output
(2) Input as appropriate diameters
(3) IM1 = Insulating Material No. 1
SM1 = Structural Material No. 1
(4) RBTO4 = DBTO4/2

Figure 59. Dimensional Inputs for Nozzle Type 4

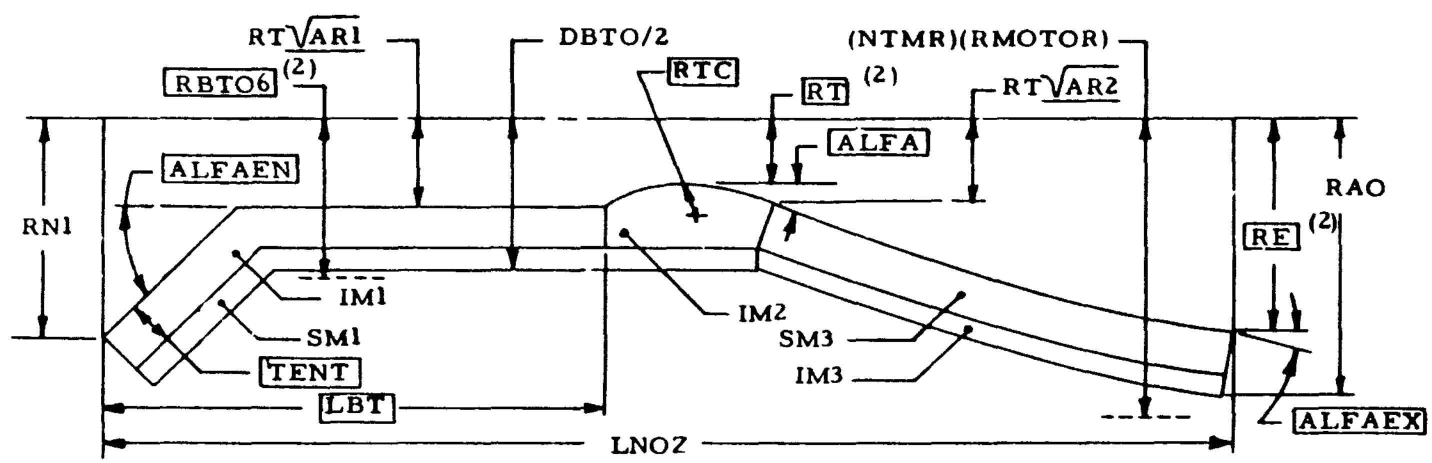
NOZZLE TYPE 5



(1) Dimensions shown in blocks or underlined are input; others are output.
(2) Input as appropriate diameters
(3) IM1 = Insulating Material No. 1
IM2 = Insulating Material No. 2
SM1 = Structural Material No. 1

Figure 60. Dimensional Inputs for Nozzle Type 5

NOZZLE TYPE 6



(1) Dimensions shown in blocks or underlined are input; all others are output
(2) Input as appropriate diameters
(3) IM1 = Insulating Material No. 1
IM2 = Insulating Material No. 2
IM3 = Insulating Material No. 3
SM1 = Structural Material No. 1
SM2 = Structural Material No. 2

Figure 61. Dimensional Inputs for Nozzle Type 6

TABLE 17

OUTPUT OF NOZZLE INPUT SUBROUTINE

PARAMETER Parameter Name	Definition and Units
OBATMX	Penalty for throat area larger than ATMAX determined in ballistic simulation (subroutine SEC3SB). Mass generation rate and mass discharge rate have not converged within 1/1000, but PMAX and PMIN have converged to within PMAX/100,000; condition is result of Mach number in propellant cavity approaching a value of one. Throat diameter has been reset internally to correspond to (0.999)(ATMAX) and the program flow has been recycled through the subroutine NOZINP for dimentional verification.
OBJAEX	Penalty for nozzle exit half-angle (ALFAEX) greater than expansion section entrance angle (ALFA) on contoured nozzle.
OBJRE	Penalty for (1) nozzle exit radius (RE) less than radius at which Insulation Material No. 2 changes to Insulation Material No. 3 for Nozzle Types 1, 2, and 6 when RE is adjusted to correct the incompatibility; or, (2) RE greater than nozzle entrance radius (RN1) for nozzle Type 3, or (3) RE greater than (RBTO-TSTR) for nozzle Type 4; or, (4) RE less than RN1 for Nozzle Type 4.
OBJRNZ	Penalty for (1) case aft opening radius (RNOZEN) not equal to nozzle entrance radius (RN1) for nozzle Types 1, 2, 5 and 6, or (2) throat radius (RT) larger than RNOZEN for Nozzle Types 3, 4 and 5.
OBJRT	Penalty for (1) nozzle throat radius (RT) greater than radius at which Insulation Material No. 1 changes to Insulation Material No. 2 (RNOZEN/ $\sqrt{ARI}$) for Nozzle Type 1, 2 and 6; or, (2) nozzle exit radius (RE) less than radius at which Insulation Material No. 2 changes to Insulation Material No. 3 for Nozzle Types 1, 2 and 6 when RT is adjusted to correct the incompatibility; or, (3) case aft opening radius (RNOZEN) less than RT for Nozzle Types 3 and 4 when RT is adjusted to correct the incompatibility; or, (4) RE less than RT for Nozzle Types 3 and 4 when RT is adjusted to correct the incompatibility; or (5) inside radius of blast tube (RT $\sqrt{ARI}$) greater than case aft opening radius (RNOZEN) for Nozzle Types 5 and 6.

Table 17

OUTPUT OF NOZZLE INPUT SUBROUTINE (contd.)

Parameter Name	Definition and Units
RE	Radius (in) of nozzle exit after completion of dimensional verification.
RT	Initial (i.e., Time = 0) radius (in) of nozzle throat after completion of dimensional verification.

INPUTS FOR BALLISTIC SIMULATION

This block of input data describes the ballistic characteristics of the propellant and motor. All data is contained in the namelist BALLST.

Output of this block is a result of comparing the incoming burn rate and pressure exponent with user-supplied limits and calculating appropriate penalties for exceeding those limits.

TABLE 18

NAMELIST/BALLST

INPUTS FOR BALLISTIC SIMULATION

Parameter Name	Default Value	Definition and Units
AUTOEB	1.0	Flag for erosive burning contribution to be calculated as follows: (Also see Note 10 and Table 19) 0.0: No erosive burning contribution, if MCRIT and XM also equal 0.0 0.0: Saderhold model with user-input values for MCRIT and XM 1.0: Saderholm model with MCRIT and XM calculated internally according to original Saderholm investigation. If this option used, do not input MCRIT and XM
BRSF	1.0	Burn rate scale factor multiplier on local propellant burn rate
CSTR70	Note 2	Characteristic velocity (nozzle end) at 70°F (ft/sec)
DELP	Note 2	Propellant cured density. Theoretical density calculated by thermochemical module is multiplied by 0.985 to obtain cured density (lb/cu in)
DELT1	Note 1	Burning time increment at which ballistic calculations are made, starting at time - 0.0 until time = TIME (sec). See Note 9.
DELT2	0.0	Burning time increment at which ballistic calculations are made, starting at time = TIME and continuing until completion of simulation. See Note 9
ETAISP	0.95	Impulse efficiency, defined as ratio of vacuum specific impulse to ideal vacuum specific impulse at the same expansion ratio and pressure. Can be calculated internally using SPP "empirical" relationships (SPPETA = T). Does not include divergence losses when supplied by this input.
FRB70	T	Search control for burn rate at 70°F, 1000 psia, RB70 (see Note 8).
FXN	T	Search control for pressure exponent, XN (see Note 8).

Table 18

NAMELIST/BALLST (contd.)

Parameter Name	Default Value	Definition and Units
GAMAC	Note 2	Ratio of specific heats in combustion chamber.
IVAC	0.0	Vacuum specific impulse, shifting equilibrium, at motor pressure and nozzle expansion ratio (lbf-sec/lbm). See Note 5.
IVACF	0.0	Vacuum specific impulse, frozen equilibrium, at motor pressure and nozzle expansion ratio (lbf-sec/lbm). See Note 5.
KRE1	Note 1	Coefficient in nozzle throat ablation model RE = KRE1*P**KRE2 where P = nozzle-end chamber stagnation pressure (psia) and RE = throat radial regression rate (in/sec)
KRE2	Note 1	Pressure exponent in nozzle throat ablation model
MC	0.0	Temperature sensitivity of characteristic velocity, m_c (per°F)
MCRIT	0.0	Critical Mach number in Saderholm erosive burning model (MACH/MCRIT)**XM. See Table 19.
MOLCND	0.0	Mole fraction of condensed species (moles per 100 gms of mixture). See Note 5.
MPCOEF	0.0093	Coefficient in propellant surface regression model RB = (MPCOEF)(MP)**MPEXP where RB = propellant surface regression rate (in/sec), MP = product of local Mach number and static pressure (psia).
MPEXP	0.71	Exponent of MP product in propellant surface regression model
PATM	0.0	Atmospheric pressure at which ballistic simulation is performed (psia). See Note 7.
PC	10^3.	Pressure used in thermochemical analysis (subroutine TCHEM) and impulse efficiency prediction (subroutine IMPEFF) for analysis with user-supplied starting conditions (first pass through subroutine COMP) (psia). After first pass, pressure used in TCHEM and IMPEFF is that predicted in the just-completed pass through COMP.

Table 18

NAMELIST/BALLST (contd.)

Parameter Name	Default Value	Definition and Units
PCUTOF	20.0	Pressure on descending portion of pressure history at which ballistic simulation will stop (psia). Should be adjusted downward if maximum motor pressure is expected to be about 200 psia.
PIK	0.0	Temperature sensitivity of pressure at a particular value of K_n, π_k (per °F)
RBMAX	10^2	Upper constraint on burn rate at 1000 psia, 70°F allowed during burn rate optimization (in/sec)
RBMIN	0.0	Lower constraint on burn rate at 1000 psia, 70°F allowed during burn rate optimization (in/sec)
RB70	Note 3	Propellant burn rate at 1000 psia, 70°F (in/sec)
RGAS	Note 2	Gas constant of combustion products in chamber (ft-lbf/lbm-°R)
TC	0.0	Chamber combustion product temperature (°R) to be used in nozzle thermal analyses if thermo-chemistry analysis is not performed in the code.
THI	0.0	Upper temperature at which ballistic simulation is to be performed (°F). See Note 4.
TIME	0.0	Time at which burn time increment, DELT2, is to start (sec).
TLO	0.0	Lower temperature at which ballistic simulation is to be performed (°F). See Note 4.
VELSON	0.0	Sonic velocity in chamber (ft/sec). See Note 6.
XM	0.0	Mach number ratio exponent in Saderholm erosive burning model. See Table 19.
XN	Note 3	Pressure exponent in propellant burn rate model RB = A*P**XN where P = local static pressure (psia) and RB = propellant surface regression rate (in/sec) A = constant coefficient Must be input (fictitious value) even when user model supplied in USERRB.

Table 18

NAMELIST/BALLST (contd.)

Parameter Name	Default Value	Definition and Units
XNMAX	10^2	Upper constraint on pressure exponent in burn rate model allowed during burn rate optimization
XNMIN	0.0	Lower constraint on pressure exponent in burn rate model allowed during burn rate optimization

NOTES:

1. Input required for all problems.
2. Input required for all problems or will be calculated internally if FORMAD or FORMIN = T.
3. Input required for all problems or must be calculated by user-input model through subroutine USERRB.
4. To perform ballistic simulation at only one temperature, input THI = TLO (default value is satisfactory).
5. Input required if impulse efficiency is predicted in subroutine IMPEFF (SPPETA=T), but propellant formulation is not input (FORMIN = F).
6. Input required if combustion stability analysis is performed in subroutine E488M2, but propellant formulation is not input (FORMIN = F).
7. Can be any value desired when trajectory simulation is performed. Vacuum thrust is calculated internally and stored for use in trajectory simulation.
8. Logical command to specify parameters that may be adjusted during optimization search. T = parameter will be maintained at input value, but will be adjusted.
9. Maximum number of time steps allowed in ballistic simulation is 100; the user should anticipate motor operating time and select DELT1 and DELT2 accordingly, remembering that fine time steps results in long execution time.
10. Regression of an ablating surface according to the model RB = (MPCOEF * MP)**MPEXP) will be calculated with default values of MPCOEF and MPEXP and used in ballistic simulation if RB > RATE = (A)P**N, unless MPCOEF = 0.0 and MPEXP = 0.0 are input. See Table 19 also.

TABLE 19

EROSIVE BURNING RATE COMBINATIONS

AUTOEB	MCRIT	XM	MPCOEF	MPEXP	Description
0.0	0.0	0.0	0.0	0.0	No erosive burning
0.0	X[a]	X	X	X	Erosive burning with user values for MCRIT, XM, MPCOEF and MPEXP
1.0	0.0	0.0	X	X	Erosive burning with internally calculated values for MCRIT and XM (see Note (b)) and user values for MPCOEF and MPEXP (see Note (c))

(a) "X" indicates user-input or default value.

(b) Saderholm model, Reference 9 and 10. MCRIT = Mach number corresponding to 250 fps. XM calculated from the relationship.

$$XM = \ln \left[0.06768 \left(\frac{P^{0.74}}{RATE} \right)^{0.4948} \right]$$

which is a curve fit to Saderholm data (XM ≥ 0.0 and RATE = burn rate without erosive burning, P = local static pressure, when local Mach number > MCRIT.

(c) Default values MPCOEF = 0.0093 and MPEXP = 0.71.

TABLE 20

OUTPUT FROM VERIFICATION OF BALLISTIC ANALYSIS INPUTS

Parameter Name	Definition and Units
OBRBMN	Penalty for propellant burn rate at 1000 psia and 70°F less than minimum limit (RBMIN)
OBRBMX	Penalty for propellant burn rate at 1000 psia and 70°F exceeding maximum limit (RBMAX)
OBXNMN	Penalty for pressure exponent in burn rate model RB = A*P**XN less than minimum limit (XNMIN)
OBXNMX	Penalty for pressure exponent in burn rate model RB = A*P**XN exceeding maximum limit (XNMAX)

THERMOCHEMICAL ANALYSIS

This collection of input data provides the information necessary to perform a thermochemical analysis of an input propellant formulation. Results of the analysis are used for (1) ballistic simulation; (2) SPP impulse efficiency subroutine; (3) combustion stability analysis. Obviously, if a thermochemical analysis is not performed and the above subsequent analyses are desired, the user must supply values for the required parameters (in namelist BALLST).

Four blocks of data are normally employed; three are namelists and one is a card which names the propellant ingredients. A fifth block of input data can be used to furnish thermochemical properties for ingredients that are not presently stored in the code (see Table 22 for what is available now); the user inputs INGIN = T in namelist CONTRL to show that this fifth block will be furnished.

Namelist	Purpose
(1)	Consists of up to four new propellant ingredients. A final card must have XX in card columns 1 and 2. Provides thermochemical properties of propellant ingredients not stored in code. (See Table 21).
(2)	Consists of a card which names the various classes of propellant ingredients. Identifies propellant ingredients according to a specified dictionary. See Table 22.
INGAMT	Provides initial weight fraction of each of the named ingredients.
INGFIX	Specifies which ingredients will be adjusted in weight fraction during optimization search.
INGLIM	Provides weight fraction limits on the searched parameters.

Output from this block of the code is the result of the thermochemical analysis.

TABLE 21

INPUTS FOR THERMOCHEMICAL PROPERTIES OF NEW INGREDIENTS

Thermochemical properties of eleven propellant ingredients are stored in the code; these are listed in and can be accessed according to the instructions given in Table 22.

The user can also furnish thermochemical properties for up to four ingredients that are not provided in the code. Data for each new ingredient is contained on a separate card. There must be a final card with XX in columns 1 and 2 to show there are no more new ingredients to be read. These new ingredients then must be associated with a generic name according to the instructions of Table 22.

The format of each card is:

5(A2. F7.4), A4, 4X, F9.1, 10X, F8.5

Column Number	Contents
1-45	Formula of ingredient with up to five kinds of atoms, where each kind is described by XXNNNNNNN, and XX = atomic symbol (left justified) NNNNNNN = atom count
46-49	Name of ingredient. Cannot be same as those in Table 22.
54-62	Enthalpy (cal/GFW), CFW = gram formula weight
73-80	Density (gm/ cu cm)

An example of a new ingredient card is:

Starting in Column	Input
1	C-10.----H-10.----FE1.-----
46	FCH
54	33000.
73	1.388

TABLE 22

INGREDIENT CARD

INPUTS TO NAME PROPELLANT INGREDIENTS

Manipulations within the code to adjust, verify and normalize the propellant formulation use functional nomenclature so that the user can have a choice of ingredients for any one function. For example, two oxidizers may be employed (identified as OXA and OXB) and either one of them may be "named" as AP, or RDX, or HMX.

The functional names are identified with a particular ingredient through use of two formated input cards. The first card is an identification card continuing up to 40 characters starting in card column one. The second card lists the names of the ingredients to fulfill a particular function. The functions must be listed exactly in the order shown below and in the columns indicated.

An example input is

INGREDIENTS - XYZ PROPELLANT
HTPB, AL_ _, AP_ _, _ _ _ _, _ _ _ _, FE2O, _ _ _ _,

Function	Card Column	Definition and Units
BIND	1 - 4	Name of propellant binder (polymer and all additives). Select from: HTPB
FUEL	6 - 9	Name of fuel. Select from AL, C, ZR,
OXA	11 - 14	Name of oxidizer A. Select from AP, RDX, HMX
OXB	16 - 19	Name of oxidizer B. Select from AP, RDX, HMX
RCATL	21 - 24	Name of liquid burn rate catalyst. None available at the present.
RCATS	26 - 29	Name of solid burn rate catalyst. Select from FE2O, FCN, ALOX.
STAB	31 - 34	Name of combustion stabilizer. Select from ZRC, ZR, ALOX, C.

Table 22

INGREDIENT CARD - INPUTS TO NAME PROPELLANT INGREDIENTS (contd.)

Code Ingredient Designation	Ingredient
AL	Aluminum
ALOX	Aluminum oxide
AP	Ammonium perchlorate
C	Carbon
FCN	Ferrocene
FE2O	Iron oxide
HMX	Cyclotetramethylenetetranitramine
HTPB	Mixture of HTPB polymer and typical cure agent, plasticizer and bond agent
RDX	Cyclotrimethylenetrinitramine
ZR	Zirconium
ZRC	Zirconium carbide

The same ingredient can be designated as more than one function. For example, OXA and OXB can both be named as AP, thus providing up to six particle size differentiations for that material. Another example is that ALOX may be employed as RCATS and STAB simultaneously.

TABLE 23

NAMELIST/INGAMT

INPUTS FOR PROPELLANT INGREDIENT WEIGHT FRACTION

Parameter Name	Default Value	Definition and Units
BIND	0.0	Weight fraction of binder
FUEL	0.0	Weight fraction of fuel
OXA(I)	0.0	Weight fraction of each of three sizes of oxidizer A (I = 1, 2, 3)
OXB(I)	0.0	Weight fraction of each of three sizes of oxidizer B (I = 1, 2, 3)
RCATL	0.0	Weight fraction of liquid burn rate catalyst
RCATS	0.0	Weight fraction of solid burn rate catalyst
STAB	0.0	Weight fraction of combustion stabilizer
DIAAP(I)	0.0	Weight mean diameter, WMD (microns) ammonium perchlorate (AP) oxidizer, I = 1, 2, 3. Used in combustion stability analysis, where the model for combustion response is based on AP.

TABLE 24

NAMELIST/INGFIX

INPUTS TO CONTROL SEARCH OF PROPELLANT FORMULATION

Parameter Name	Default Value	Definition and Units
FBIND	T	Search control for binder weight fraction. See Note 1.
FFUEL	T	Search control for fuel weight fraction. See Note 1.
FOXA(1,2,3)	T,T,T	Search control for oxidizer A weight fraction. See Note 1.
FOXB(1,2,3)	T,T,T	Search control for oxidizer B weight fraction. See Note 1.
FRCL	T	Search control for liquid burn rate catalyst weight fraction. See Note 1.
FRCS	T	Search control for solid burn rate catalyst weight fraction. See Note 1.
FSTABP	T	Search control for combustion stabilizer weight fraction. See Note 1.

NOTES

1. Logical command to specify parameters that may be adjusted during optimization search. T = parameter will be maintained constant at input value; F = parameter will not be maintained at input value, but will be adjusted.

TABLE 25

NAMELIST/INGLIM

INPUTS TO LIMIT PROPELLANT INGREDIENTS

Parameter Name	Default Value	Definition and Units
FUELMX	1.0	Maximum weight fraction of fuel
RCLMX	1.0	Maximum weight fraction of liquid burn rate catalyst
RCSMX	1.0	Maximum weight fraction of solid burn rate catalyst
TSMAX	1.0	Maximum weight fraction of total solids
EOMLIM	10^3	Maximum limit on propellant rheological property (as defined by user)
EOMMDL	F	Propellant rheology model is supplied by user (T = yes, F = no)

TABLE 26

OUTPUT OF THERMOCHEMICAL ANALYSIS

PROPELLANT INFORMATION

The first block of output data organizes and summarizes the input data, according to the following table.

Function	Names	Amounts	Fixes	Limits
---	---	---	---	---
---	---	---	---	---
---	---	---	---	---

where:

Function	=	Purpose of ingredient (binder, oxidizer, etc.)
Name	=	Identify of ingredient serving a designated function
Amount	=	Weight fraction of given function input by user
Fixes	=	Flag for weight fraction of specified function to be adjusted during optimization (T = will be maintained at input value; F = will not be maintained at input value, but will be adjusted)
Limits	=	Weight fraction limits on specified function input by user

MESSAGES

The second block of output data consists of messages that result from verification analyses performed by the subroutine TCHEM (and its called subroutines) and from instructions provided through user inputs

a. "Fixed liquid content makes solids exceed TSMAX" (which terminates execution)

b. "Fixed liquid content fixes total solids = ______"

c. "Low limit on RCATL set by TSMAX and fixed BIND = ______"

d. "Low limit on RCATL exceeds RCLMAX" (which terminates execution)

e. "Low limit on BIND set by TSMAX and fixed RCATL"

f. "Total solids limit is ______"

Table 26

OUTPUT OF THERMOCHEMICAL ANALYSIS (contd.)

PENALTIES

The third block of output data lists the penalties that are calculated in the TCHEM module as a result of verifying the incoming propellant formulation and adjusting it if necessary.

Parameter Name	Definition
OBFUEL	Penalty for FUEL weight fraction (1) less than zero, or (2) greater than input maximum limit
OBJBND	Penalty for BIND weight fraction less than lower limit on binder (LLB), a value calculated internally from inputs.
OBJRCL	Penalty for RCL weight fraction (1) less than zero; or, (2) greater than input maximum RCLMX.
OBJRCS	Penalty for weight fraction of RCATS (1) less than zero; or, (2) greater than input maximum RCSMX.
OBJTS	Penalty for weight fraction of all solid ingredients (TOTSOL) exceeding input maximum limit (TSMAX).
OBOXA(I)	Penalty for weight fraction of OXA(I) less than zero (I = 1,2,3).
OBOXB(I)	Penalty for weight fraction of OXB(I) less than zero (I = 1,2,3).
OBSTAB	Penalty for weight fraction of STAB less than zero.

VERIFIED FORMULATION

The fourth block of output data is the propellant ingredients and their weight fractions that will be used in the thermochemical analysis. These weight fractions may be different from those input because of the previous verification checks.

RESULTS OF THERMOCHEMICAL ANALYSIS

The fifth block of output data consists of the results of the thermochemical analysis. MOLCND and IVACF are calculated only if impulse efficiency is to be calculated by SPP model (SPPETA = T). These data are as follows:

Table 26

OUTPUT OF THERMOCHEMICAL ANALYSIS (contd.)

Parameter Name	Definition and Units
PC	Chamber pressure (psia) at which analysis is performed. Internally set at 1000 psia or user input for the initial evaluation; subsequent evaluations use the average chamber pressure (PBAR) from the preceeding evaluation at low temperature if a two-temperature problem is being run.
NOZER	Nozzle expansion ratio at which analysis is performed, based on initial throat and exit areas.
DELP	Propellant density (lbm/cu in). Theoretical number has been multiplied by 0.985 to correct for cure shrinkage and cool-down from cure temperature.
RGAS	Combustion product gas constant (ft-lbf/lbm-°R).
GAMAC	Ratio of specific heats in combustion chamber.
SON VEL	Speed of sound (ft/sec) in combustion chamber.
CSTAR70	Characteristic velocity at 70°F (ft/sec).
IVAC	Vacuum specific impulse (lbf-sec/lbm) at given pressure and expansion ratio, shifting equilibrium, no divergence losses.
IVACF	Vacuum specific impulse (lbf-sec/lbm) at given pressure and expansion ratio, frozen equilibrium, no divergence losses.
MOLCND	Mole fraction of condensed species (moles per 100 gms of mixture).
TC	Chamber combustion product temperature (°R).

PERFORMANCE REQUIREMENTS AND DESIGN CONSTRAINTS

This block of input data provides the information whereby (1) the statistical extremes of ballistic performance can be calculated; (2) constraints on motor characteristics can be compared to calculated values; (3) miscellaneous performance parameters can be compared to requirements. All data is contained in the namelist REQMTS.

There is no output from this section of the code.

TABLE 27

NAMELIST/REQMTS

INPUTS FOR PERFORMANCE REQUIREMENTS AND DESIGN CONSTRAINTS

Parameter Name	Default Value	Definition and Units
ACLIM	10^6.	Maximum acceleration limit (g's) based on nominal thrust; drag-free unless trajectory simulation is performed (FTRAJ=T); at upper temperature when ballistic simulation is performed at two temperatures.
CVF	0.0	Coefficient of variation of ignition thrust (% x 0.01)
CVI	0.0	Coefficient of variation of total impulse (% x 0.01)
CVP	0.0	Coefficient of variation of maximum pressure (% x 0.01)
CVPI	0.0	Coefficient of variation of ignition pressure (% x 0.01)
CVTB	0.0	Coefficient of variation of burn time (% x 0.01)
DELVRQ	0.0	Required change in velocity (ft/sec) during motor operation (velocity at burnout minus launch velocity)
DMOTMX	10^3.	Maximum motor diameter limit (in)
FMAX	10^6.	Maximum ignition thrust limit (lbf), at first time point in simulation, upper three-sigma, at upper temperature when ballistic simulation is performed at two temperatures.
FMIN	0.0	Minimum ignition thrust limit (lbf), at first time point in simulation, lower three-sigma, at lower temperature when ballistic simulation is performed at two temperatures.
FSULT	1.0	Factor of safety based on ultimate material capabilities
FSYLD	1.0	Factor of safety based on yield material capabilities
ITREQ	0.0	Required total impulse (lbf-sec); lower three-sigma; at lower temperature when ballistic simulation is performed at two temperatures
LMOTMX	10^3.	Total motor length limit (in)
MACLIM	0.9	Maximum Mach number limit in propellant cavity, at lower temperature when ballistic simulation is performed at two temperatures.

Table 27

NAMELIST/REQMTS (contd.)

Parameter Name	Default Value	Definition and Units
PMXLIM	10^4	Maximum nominal head-end pressure limit (psia), at upper temperature when ballistic simulation is performed at two temperatures
SCALE	1.0	Multiplier on expected value of optimized parameter (PAYOFF) to cause it to be approximately equal to 2000.
TBMNLM	0.0	Minimum burn time limit (sec), lower three-sigma, at upper temperature when ballistic simulation is performed at two temperatures
TBMXLM	10^2	Maximum burn time limit (sec), upper three-sigma, at lower temperature when ballistic simulation is performed at two temperatures
TTTRQ	10^3	Required time-to-termination (sec)
WMOTMX	10^6	Maximum total motor weight limit (lbm).
VTRQ	0.0	Required velocity (ft/sec) at termination
WNP	0.0	Non-propulsive weight (lbm); should include warhead, wings, tunnels, etc.
WOTHER	0.0	Inert weight (lbm) in the propulsion unit that is not accounted for elsewhere through specific calculation. Should include igniter, safe-and-arm device, environmental closures, etc.

BALLISTIC SIMULATION

This block of data consists of output only and provides the detailed results of the ballistic simulation. The objective of all calculations up to this point was to generate the data needed to perform the ballistic simulation; all subsequent calculations use some result from the baliistic simulation as an input for that particular analysis.

The description of the simulation output is divided into three major catagories:

(1) Grain geometry description
(2) Miscellaneous inputs
(3) Time-history output

The grain geometry descriptions printed by the simulation module are slightly different for the different propellant configurations contained in the code. Therefore separate tables listing the output have been provided.

Table 28 - Grain Types 1 and 2
Table 29 - Grain Type 3
Table 30 - Grain Type 4
Table 31 - Grain Type 5

Then two additional tables give the other output catagories

Table 32 - Miscellaneous inputs
Table 33 - Time-history output

If the ballistic simulation is performed at two different grain soak temperatures (because THI not equal to TLO), the complete output described above is given for the high temperature simulation. Then the output describing the grain geometry is suppressed for the second simulation at low temperature conditions, but the ballistic results are presented.

TABLE 28

OUTPUT OF BALLISTIC SIMULATION

GRAIN GEOMETRY OF GRAIN TYPE 1 (STAR) AND

TYPE 2 (WAGON WHEEL)[1]

*****PLANE DIMENSIONS AT INITIAL CONDITIONS*****

LENGTH	Axial distance (in) downstream from Plane 1; corresponds to L4T1 through L14T1.
TAUW	Propellant web thickness (in); corresponds to TAUW.
R2	Radius (in) on star tip; corresponds to R2A1 through R2A14.
R3	Blend radius (in) between sides of wagon wheel propellant point. Not used for Type 1 star grain.
R5	Fillet radius (in) between propellant point and propellant web; corresponds to R5A1 through R5A14.
LS1	Height (in) of propellant point.
LA	Length (in) along one side of propellant point in wagon wheel configuration. Not used for Type 1 star grain.
ALPHA01	Included half-angle (deg) of propellant point (star) and inner-most portion of propellant point (wagon wheel).
ALPHA02	Included half-angle (deg) of base portion of propellant point on wagon wheel for which it is always equal to zero. Not used on star grain.
RF	Outside radius (in) of propellant; corresponds to RFA1 through RFA14.
NO	Number of propellant slots (or propellant points); corresponds to NSLOTS.
NUMBER OF INPUT PLANES	Counted by code
INITIAL PERIMETER	Perimeter (in) of port at specified plane
INITIAL PORT AREA (see Note 2)	Port area (sq in) at specified plane

Table 28

OUTPUT OF BALLISTIC SIMULATION (contd.)
GRAIN TYPE 1 AND TYPE 2 GRAIN GEOMETRY

*****HEAD END COORDINATES*****

(OR)

*****NOZZLE END COORDINATES*****

RADIUS	Radius (in) from motor centerline to propellant-liner interface. Corresponds to RECH(I) or RECN(I).
LENGTH	Axial distance (in) forward of Plane 1 or aft of Plane 14 to propellant-liner interface at radius RADIUS. Corresponds to HECH(I) or HECN(I).
SINE	Sine of angle between motor centerline and a straight line connecting two radius-length pairs.
BURNING RATE	Indicates erosive burning not included (=1) on forward-facing surface at head-end of motor or aft-facing surface at head-end of motor or aft-facing surface at nozzle-end of grain.

*****INITIAL VOLUMES*****

CHAMBER VOLUME	Volume (cu in) inside liner (see Note 3).
PROPELLANT VOLUME	Volume (cu in) of propellant.
PORT VOLUME	Volume (cu in) of port (see Note 3).
HEAD	Volumes located forward of Plane 1.
CYLINDRICAL	Volumes located between Plane 1 and Plane 14.
NOZZLE	Volumes located aft of Plane 14.
TOTAL	Sum of head, cylindrical and nozzle volumes.

Internal code designations of individual volumes are shown below.

	Head	Cylindrical	Nozzle	Total
Chamber Volume	VCEH	VCC	VCEN	VC
Propellant Vol.	VFH	VFC	VFN	VF
Inert Sliver Vol.	VSH	VSC	VSN	VS
Port Volume	VPH	VPC	VPN	VP

Table 28

OUTPUT OF BALLISTIC SIMULATION (contd.)
GRAIN TYPE 1 AND TYPE 2 GRAIN GEOMETRY

NOTES:

(1) Corresponding grain dimensions are also given in "Output of Grain Dimension Setup" listed earlier.
(2) Remaining parameters are not used in this simulation.
(3) Includes only that part of chamber occupied by propellant.

TABLE 29

OUTPUT OF BALLISTIC SIMULATION
GRAIN GEOMETRY OF GRAIN TYPE 3 (FINOCYL)[1]

*****PLANE DIMENSIONS AT INITIAL CONDITIONS*****

LENGTH	Axial distance (in) downstream from Plane 1; corresponds to L4T1 through L14T1.
NO	Number of propellant slots; corresponds to NSLOTS.
RF	Outside radius (in) of propellant; corresponds to RFA1 through RFA14.
R2	Port radius (in); corresponds to R2A1 through R2A14.
R3	Blend radius (in) between slot side and center port. Always zero in this simulation.
R4	Slot fillet radius (in); corresponds to R4A1 through R4A14.
R5	Slot depth radius (in); corresponds to R5A1 through R5A14.
ALPH01	Angle (deg) on side of longitudinal slot; corresponds to ALPHA1 through ALPH14.
NUMBER OF INPUT PLANES	Counted by code
INITIAL PERIMETER	Perimeter (in) of port at specified plane
INITIAL PORT AREA	Port area (sq in) at specified plane

*****HEAD END COORDINATES*****

(OR)

*****NOZZLE END COORDINATES*****

RADIUS	Radius (in) from motor centerline to propellant-liner interface. Corresponds to RECH(I) or RECN(I).
LENGTH	Axial distance (in) forward of Plane 1 or aft of Plane 14 to propellant-liner interface at radius RADIUS. Corresponds to HECH(I) or HECN(I).
SINE	Sine of angle between motor centerline and a straight line connecting two radius-length pairs.

Table 29

OUTPUT OF BALLISTIC SIMULATION - GRAIN TYPE 3 GRAIN GEOMETRY (contd.)

BURNING RATE CODE	Indicates erosive burning not included (=1) on forward-facing surface at head-end of motor or aft-facing surface at nozzle-end of grain.

*****INITIAL VOLUMES*****

CHAMBER VOLUME	Volume (cu in) inside liner (see Note 3).
PROPELLANT VOLUME	Volume (cu in) of propellant.
PORT VOLUME	Volume (cu in) of port (see Note 3).
HEAD	Volumes located forward of Plane 1.
CYLINDRICAL	Volumes located between Plane 1 and Plane 14.
NOZZLE	Volumes located aft of Plane 14.
TOTAL	Sum of head, cylindrical and nozzle volumes.

Internal code designations of individual volumes are shown below.

	Head	Cylindrical	Nozzle	Total
Chamber Volume	VCEH	VCC	VCEN	VC
Propellant Vol.	VFH	VFC	VFN	VF
Inert Sliver Vol.	VSH	VSC	VSN	VS
Port Volume	VPH	VPC	VPN	VP

(1) Corresponding grain dimensions are also given in "Output of Grain Dimension Setup" listed earlier.

(2) Two parameters (LS1 and TAUS) are listed but are not used in this simulation.

(3) Includes only that part of chamber occupied by propellant.

TABLE 30

OUTPUT OF BALLISTIC SIMULATION

GRAIN GEOMETRY OF GRAIN TYPE 4 (CONOCYL)[1]

*****PLANE DIMENSIONS AT INITIAL CONDITIONS*****

LENGTH	Axial distance (in) downstream from Plane 1; corresponds to L4T1 through L14T1.
RF	Outside radius (in) of propellant; corresponds to RFA1 through RFA14.
R2	Port radius (in); corresponds to R2A3 through R2A14.
R5	Slot depth radius (in); corresponds to R5A3 through R5A14. Always equal to R2A3-R2A14 in this simulation.
TAUMAX	Maximum web thickness (in) contained in subsequent table of burning surface perimeter and port area versus web thickness.
A(F+SL)	Cross-section area (sq in) of propellant plus inert sliver (if any), an output resulting from the perimeter-port area-distance burned matrix describing the forward end of the conocyl grain. Must be less than A-LIMIT calculated from RF.
A-LIMIT	Cross-section area (sq in) represented by the propellant outside radius RF at Plane 1 and 2 in this simulation.
THICKNESS	Distance (in) burned.
PERIMETER	Perimeter (in) of burning surface at Planes 1 and 2 corresponding to distance burned matrix THICKNESS.
PORT AREA	Cross-sectional port area (sq in) at Planes 1 and 2 corresponding to distance burned matrix THICKNESS.

NUMBER OF INPUT PLANES	Counted by code
INITIAL PERIMETER	Perimeter (in) of port at specified plane
INITIAL PORT AREA (see Note 2)	Port area (sq in) at specified plane

Table 30

OUTPUT OF BALLISTIC SIMULATION (contd.)
GRAIN GEOMETRY OF GRAIN TYPE 4

*****HEAD END COORDINATES*****

(OR)

*****NOZZLE END COORDINATES*****

RADIUS	Radius (in) from motor centerline to propellant-liner interface. Corresponds to RECH(I) or RECN(I).
LENGTH	Axial distance (in) forward of Plane 1 or aft of Plane 14 to propellant-liner interface at radius RADIUS. Corresponds to HECH(I) or HECN(I).
SINE	Sine of angle between motor centerline and a straight line connecting two radius-length pairs.
BURNING RATE CODE	Indicates erosive burning not included (=1) on forward-facing surface at head-end of motor or aft-facing surface at nozzle-end of grain.

*****INITIAL VOLUMES*****

CHAMBER VOLUME	Volume (cu in) inside liner (see Note 3).
PROPELLANT VOLUME	Volume (cu in) of propellant
PORT VOLUME	Volume (cu in) of port (see Note 3).
HEAD	Volumes located forward of Plane 1.
CYLINDRICAL	Volumes located between Plane 1 and Plane 14.
NOZZLE	Volumes located aft of Plane 14.
TOTAL	Sum of head, cylindrical and nozzle volumes.

Internal code designations of individual volumes are shown below.

	Head	Cylindrical	Nozzle	Total
Chamber Volume	VCEH	VCC	VCEN	VC
Propellant Vol.	VFH	VFC	VFN	VF
Inert Sliver Vol.	VSH	VSC	VSN	VS
Port Volume	VPH	VPC	VPN	VP

Table 30

OUTPUT OF BALLISTIC SIMULATION (contd.)
GRAIN GEOMETRY OF GRAIN TYPE 4

NOTES:

(1) Corresponding grain dimensions are also given in "Output of Grain Dimension Setup" listed earlier.
(2) One parameter (TAUS) is listed but is not used in this simulation.
(3) Includes only that part of chamber occupied by propellant.

TABLE 31

OUTPUT OF BALLISTIC SIMULATION
GRAIN GEOMETRY OF GRAIN TYPE 5 (CP)[1]

*****PLANE DIMENSIONS AT INITIAL CONDITIONS*****

LENGTH	Axial distance (in) downstream from Plane 1; corresponds to L4T1 through L14T1.
RF	Outside radius (in) of propellant; corresponds to RFA1 through RFA14.
R2	Port radius (in); corresponds to R2A1 through R2A14.
R5	Slot depth radius (in); corresponds to R5A1 through R5A14. Always equal to R2A1-R2A14 in this simulation.
NUMBER OF INPUT PLANES	Counted by code
INITIAL PERIMETER	Perimeter (in) of port at specified plane
INITIAL PORT AREA (See Note 2)	Port area (sq in) at specified plane

*****HEAD END COORDINATES*****

(OR)

*****NOZZLE END COORDINATES*****

RADIUS	Radius (in) from motor centerline to propellant-liner interface. Corresponds to RECH(I) or RECN(I).
LENGTH	Axial distance (in) forward of Plane 1 or aft of Plane 14 to propellant-liner interface at radius RADIUS. Corresponds to HECH(I) or HECN(I).
SINE	Sine of angle between motor centerline and a straight line connecting two radius-length pairs.
BURNING RATE	Indicates erosive burning not included (=1) on forward-facing surface at head-end of motor or aft-facing surface at nozzle-end of grain.

Table 31

OUTPUT OF BALLISTIC SIMULATION (contd.)
GRAIN GEOMETRY OF GRAIN TYPE 5

*****INITIAL VOLUMES*****

CHAMBER VOLUME	Volume (cu in) inside liner (see Note 3).
PROPELLANT VOLUME	Volume (cu in) of propellant.
PORT VOLUME	Volume (cu in) of port (see Note 3).
HEAD	Volumes located forward of Plane 1.
CYLINDRICAL	Volumes located between Plane 1 and Plane 14.
NOZZLE	Volumes located aft of Plane 14.
TOTAL	Sum of head, cylindrical and nozzle volumes.

Internal code designations of individual volumes are shown below.

	Head	Cylindrical	Nozzle	Total
Chamber Volume	VCEH	VCC	VCEN	VC
Propellant Vol.	VFH	VFC	VFN	VF
Inert Sliver Vol.	VSH	VSC	VSN	VS
Port Volume	VPH	VPC	VPN	VP

NOTES:

(1) Corresponding grain dimensions are also given in "Output of Grain Dimension Setup" listed earlier.
(2) Remaining parameters are not used in this simulation.
(3) Includes only that part of chamber occupied by propellant.

TABLE 32

OUTPUT OF BALLISTIC SIMULATION

MISCELLANEOUS INPUTS TO BALLISTIC ANALYSIS

*****NOZZLE DIAMETER INPUTS*****

NOZZLE CODE = 2	Indicates that nozzle throat ablation model is RE = KRE1*P**KRE2
DT-INITIAL	Initial throat diameter (in); corresponds to DTI.
KRE1	Coefficient in nozzle throat ablation model.
KRE2	Pressure exponent in nozzle throat ablation model.
DIA-EXIT	Inside diameter (in.) of nozzle exit; corresponds to DE.

*****TIME INCREMENT INPUTS*****

TIME	Time (sec) from zero at which time increments for ballistic simulation take effect. User can select one more other than zero through the TIME input in NAMELIST/BALLST/.
DELTA-TIME	Time increment at which ballistic simulation is performed, as specified by inputs DELT1 and DELT2 in NAMELIST/BALLST/.

*****BURNING RATE INPUTS*****

P-COEFFICIENT	Coefficient (a) in propellant burning rate model $r = ap^n$ Calculated in code from RB70, or RBHI, or RBLO and XN, where RB70 = Burn rate (in/sec) at 1000 psia and 70°F RBHI = Burn rate (in/sec) at 1000 psia and input high temperature RBLO = Burn rate (in/sec) at 1000 psia and input low temperature XN = Pressure exponent in burn rate model.
P-EXPONENT	Pressure exponent (n) in propellant burn rate model; corresponds to XN in NAMELIST/BALLST/.

Table 32

OUTPUT OF BALLISTIC SIMULATION (contd.)
MISCELLANEOUS INPUTS TO BALLISTIC ANALYSIS

M-CRITICAL	Critical Mach number in Saderholm erosive burning model (MACH/MCRIT)**XM; corresponds to MCRIT in NAMELIST/BALLST/.
M-EXPONENT	Exponent in Saderholm erosive burning model; corresponds to XM in NAMELIST/BALLST/.
MP-COEFFICIENT	Coefficient in propellant surface regression model; corresponds to MPCOEF in NAMELIST/BALLST/ RB = (MPCOEF)(MP)**MPEXP where RB = propellant surface regression (in/sec) MP = product of local Mach number and static pressure (psia).
MP-EXPONENT	Exponent of MP product in propellant surface regression model; corresponds to MPEXP in NAMELIST/BALLST/.

*****BALLISTIC INPUTS*****

CSTAR	Characteristic velocity (ft/sec) used in current ballistic simulation; corresponds to CSTR70, CSTRHI or CSTRLO, as appropriate.
DENSITY	Density (lb/cu in) of propellant; corresponds to DELP in NAMELIST/BALLST/.
GAMMA	Ratio of specific heats in chamber; corresponds to GAMAC in NAMELIST/BALLST/.
R-GAS	Gas constant of combustion products in chamber (ft-lbf/lbm-°R); corresponds to RGAS in NAMELIST/BALLST/.
CM	Impulse efficiency; corresponds to ETAISP in NAMELIST/BALLST/.
HALF-ANGLE	Nozzle divergence half-angle (deg); corresponds to (ALFA + ALFAEX)/2.0 when contoured nozzle is specified.
P-ATMOS	Atmospheric pressure (psia); corresponds to PATM in NAMELIST/BALLST/.

TABLE 33

OUTPUT OF BALLISTIC SIMULATION

TIME-HISTORY OUTPUTS(1)

*****BALLISTIC PERFORMANCE OUTPUTS*****(2)

TIME (TIME)	Time (sec) elapsed in the simulation from zero.
P-HEAD (PH)	Chamber pressure (psia) at the head end of the grain.
P-STAG-NOZZLE (PON)	Stagnation pressure (psia) at the nozzle end of the grain.
THRUST (F)	Motor thrust (lbf).
MASS FLOW (WDOT)	Mass flow rate (lbm/sec) through the nozzle throat.
THROAT AREA (AT)	Nozzle throat area (sq in).
PORT AREA (AP)	Port area (sq in) of the nozzle end of the grain.
INT-PHDT (PHDT)	Integral of head-end chamber pressure (psia-sec).
INT-PSNDT (PONDT)	Integral of nozzle-end stagnation pressure (psia-sec).
IMPULSE (FDT)	Total impulse or the integral of thrust-time (lbf-sec).
FUEL WEIGHT (WF)	Total weight (lbm) of unburned fuel at the beginning of each time increment.
EXIT AREA (AE)	Area (sq in) of the nozzle exit.
MAX MACH NO (MAXMAC)	Mach number at the plane that has the highest Mach number.
EXP. RATIO (EPS)	Nozzle expansion ratio; exit area/throat area.
ITERATIONS (NRUN)	Number of iterations on pressure required to balance mass discharge rate with mass generation rate within 0.05%.
TOTAL SURFACE (AS)	Total geometric propellant burning surface (sq in) used in ballistic simulation at given time point.

Table 33

OUTPUT OF BALLISTIC SIMULATION (contd.)
TIME-HISTORY OUTPUTS

--------------INTERNAL CONDITIONS AT TIME = 0.0(3)------------------

*****HEAD END*****

(and)

*****NOZZLE END*****

TAU BURNED - (TAUHED, TAUNOZ)	Distance (in) propellant burned on the head-end or nozzle-end regions of the grain.
RATE TYPE-END (MR END)	Indicates erosive burning not included (= 1) on forward-facing surface at head-end or aft-facing surface at nozzle-end of grain.
RATE TYPE-INT (MRINT)	Indicates if erosive burning is (= 2) or is not (= 1) included in port region of head-end or nozzle-end regions. Value is set by AUTOEB in NAMELIST/BALLST/.
SCALE FACTOR - (SFHEAD, SFNOZ)	Burn rate scale factor for the head-end or nozzle-end regions of the propellant grain; corresponds to BRSF.
STATION	Defined in Figures 61 & 62, following.
SURFACE AREA	Total cumulative surface area (sq in) from station 1 to given station. (Zero at Station 1 for head-end. HDASE and ASINTN(4) at Station 2 and 3; ASH and ASN at Station 4, for head-end and nozzle-end, respectively).
PORT AREA	Area (sq in) of port at given station. For Station 1 of head-end and Station 4 of nozzle-end, it is area of circle of radius RF. (HDAPE at Station 1, APHED for Stations 2, 3 and 4 for head-end; APNOZ at Stations 1, 2, and 3, NZAPE at Station 4 for nozzle-end).
FUEL VOLUME	Propellant volume (cu in) from Station 1 to given station. (VFH for head-end, VF for nozzle-end because it is cumulative).
PRESSURE	Static pressure (psia) at given station (HDPI and NZPl at Station 1, HDP2 and NZP2 at Stations 2 and 3, HDP4 and NXP4 at Station 4, for head-end and nozzle-end, respectively).

Table 33

OUTPUT OF BALLISTIC SIMULATION (contd.)
TIME-HISTORY OUTPUTS

TEMPERATURE	Combustion gas static temperature (°R) at given station (HDT1 and NZT1 at Station 1, HDT2 and NZT2 at Stations 2 and 3, HDT4 and NZT4 at Station 4, for head-end and nozzle-end, respectively).
DENSITY	Density (lbm/cu in) of combustion gas at given station (HDDLT1 and NZDLT1 for Station 1, HDDLT2 and NZDLT2 for Stations 2 and 3, HDDLT4 and NZDLT4 for Station 4, for head-end and nozzle-end, respectively).
VELOCITY	Velocity (ft/sec) of combustion gas at given station (HDU1 and NZU1 for Station 1, HDU2 and NZU2 for Stations 2 and 3, HDU4 and NZU4 for Stations 4, for head-end and nozzle-end, respectively.
MASS FLOW	Mass flow rate (lbm/sec) of combustion gas moving past given station (HDWDT1 and NZWDT1 for Station 1, HDWDT2 and NZWDT2 for Stations 2 and 3, HDWDT4 and NZWDT4 for Station 4, for head-end and nozzle-end respectively).
MACH NO.	Mach number of combustion gas moving past given station (HDMC1 and NZMC1 for Station 1, HDMC2 and NZMC2 for Stations 2 and 3, HDMC4 and NZMC4 for Station 4, for head-end and nozzle-end, respectively).
BURNING RATE	Instantaneous propellant burning rate (in/sec) at given station (HDRT1 and NZRT1 for Station 1, HDRT2 and NZRT2 for Stations 2 and 3, HDRT4 and NZRT4 for Station 4, for head-end and nozzle-end, respectively).

*****CYLINDRICAL SECTION*****

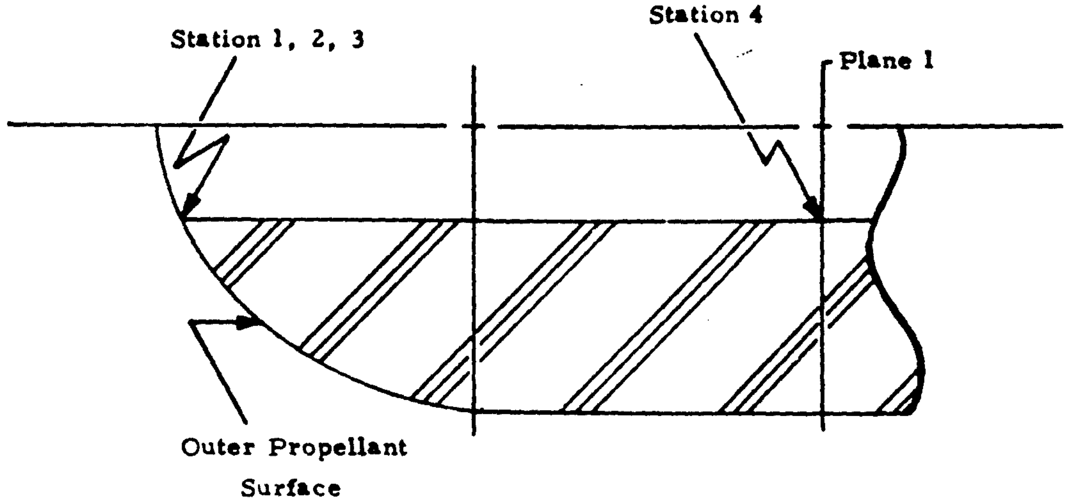
PLANE	Plane number (1 through 14).
LENGTH (PLANE (I, 3))	Distance (in) from Plane 1 to Plane I.
TAU BURNED (PLANE (I, 71))	Total thickness (in) of propellant that has burned at Plane I up to the elapsed time listed.
PERIMETER (PLANE (I, 72))	Perimeter (in) of the port at Plane I.

Table 33

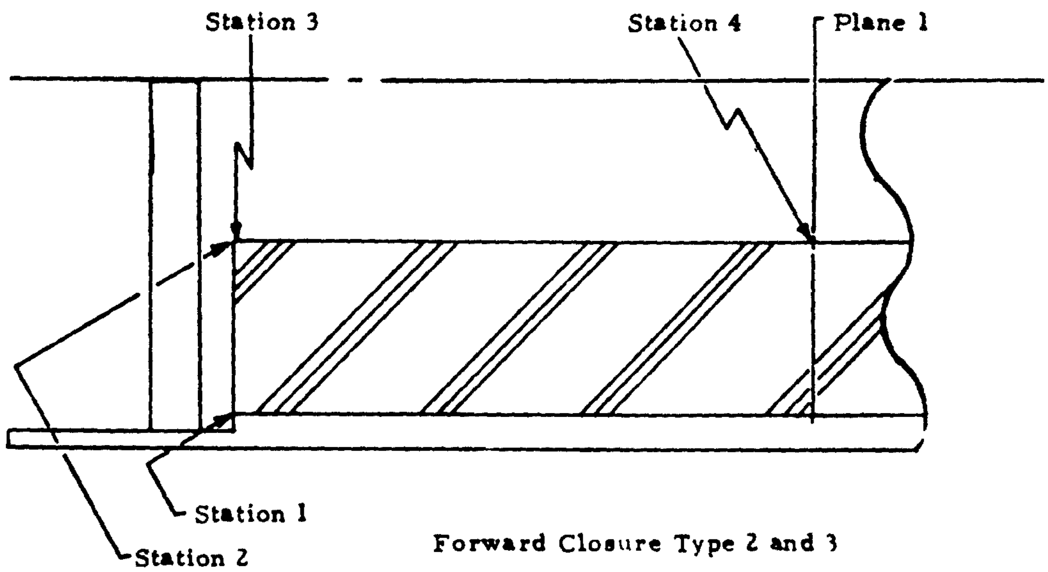
OUTPUT OF BALLISTIC SIMULATION (contd.)
TIME-HISTORY OUTPUTS

SURFACE AREA (AS)	Cumulative propellant burning surface (sq in) from Station 1 in head-end to Plane I.
PORT AREA (PLANE (I, 73))	Port area (sq in) at Plane I.
FUEL VOLUME (VF)	Cumulative propellant volume (cu in) from Station 1 in head-end to Plane I.
PRESSURE (PLANE (I, 77))	Static pressure (psia) at Plane I.
TEMPERATURE (PLANE (I, 78))	Combustion gas static temperature (°R) at Plane I.
DENSITY (PLANE (I, 79))	Density (lbm/cu in) of combustion gas at Plane I.
VELOCITY (PLANE (I, 80))	Velocity (ft/sec) of combustion gas past Plane I.
MASS FLOW (PLANE (I, 84))	Mass flow rate (lbm/sec) of combustion gas past Plane I.
MACH NO (PLANE (I, 81))	Mach number of combustion gas moving past Plane I.
RATE EQUATION	Indicates the burn rate equation in the code-supplied burn rate subroutine that is being used at the specified plane and elapsed time 1.0 RB = (BRSF)(A)P^{XN} 2.0 RB = (BRSF)(A)P^{XN}(M/MCRIT)^{XM} 3.0 RB = (MPCOEF)(MP)^{MPEXP} The equation producing the largest burn rate is used.
SCALE FACTOR (PLANE (I, 82))	Burn rate scale factor; corresponds to BRSF.
BURNING RATE (PLANE (I, 83))	Propellant burning rate (in/sec) at Plane I.

(1) Neumonic symbols in parenthesis are internal code parameter names.
(2) This group of outputs is printed at every time point at which simulation is performed.
(3) This group of outputs is printed only for the initial (time = 0.0) time point.
(4) ASINTN initially is internal (lateral) surface between Stations 1 and 2 at nozzle end; it is then updated to become the cummulative burning surface at Station 2/3 at the nozzle end.

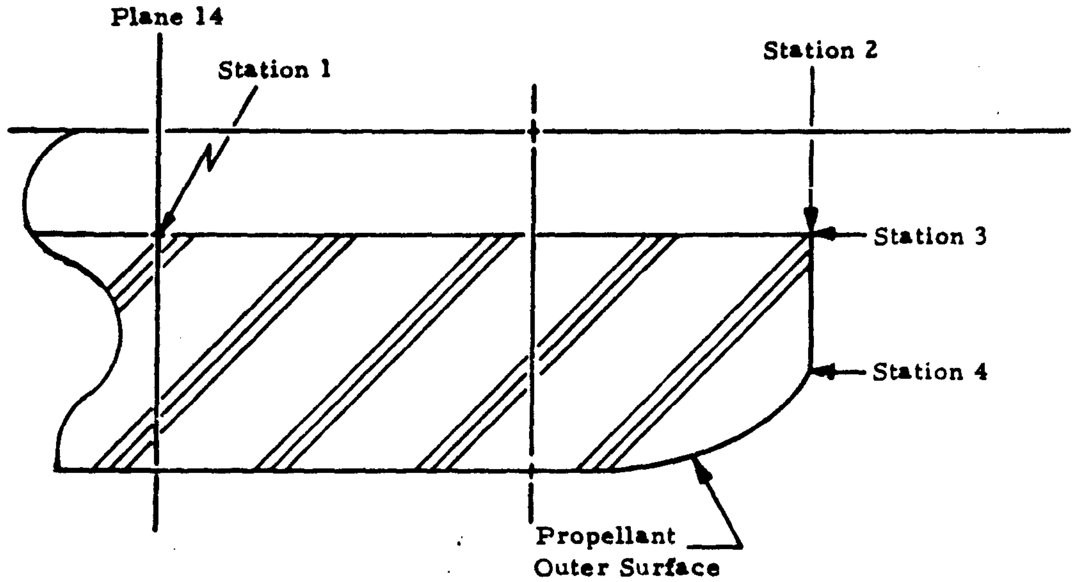


Forward Closure Type 1

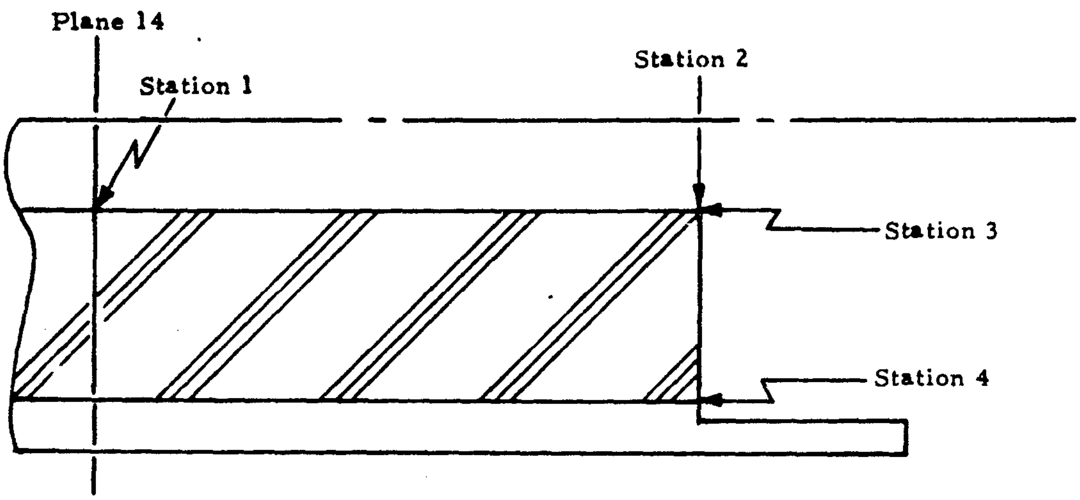


Forward Closure Type 2 and 3

Figure 62. Location of Stations for Ballistic Simulation in Head-end of Grain



Aft Closure Type 1



Aft Closure Type 2

Figure 63. Location of Stations for Ballistic Simulation in Nozzle-end Of Grain

COMPARISON WITH REQUIREMENTS AND CONSTRAINTS

This block of code is output only and is the result of comparing results of the ballistic simulation with requirements. It also lists design pressures that will be used in subsequent structural analyses. Several representative ballistic parameters are calculated for information purposes and for use in subsequent calculations.

If a two-temperature problem is being run, the subject results follow the appropriate ballistic simulation. First, the ballistic simulation at high temperature is performed, followed by the comparisons described here (Table 34); then the low temperature simulation is performed, followed by its appropriate comparisons (Table 35). If the ballistic simulation is performed at a single temperature, comparisons are given in Table 36.

There is no input associated with this block of output.

TABLE 34

OUTPUT OF PERFORMANCE COMPARISON WITH REQUIREMENTS AT HIGH TEMPERATURE

Parameter Name	Definition and Units
FBARHI	Nominal average thrust (lbf) from time = zero to TBHI
FIGMAX	Upper three-sigma ignition thrust (lbf), at first time point in ballistic simulation at high temperature
ISPHI	Specific impulse (lbf-sec/lbm) at high temperature
MEOP	Maximum expected operating pressure (psia), maximum nominal head-end pressure at high temperature plus three-sigma statistical variation
OBJFMX	Penalty for ignition thrust FIGMAX exceeding maximum limit (FMAX)
OBPMAX	Penalty for maximum nominal head-end pressure (PH) during ballistic simulation greater than maximum limit (PHMAX)
OBTBMN	Penalty for burn time (TBMIN) less than minimum limit (TBMNLM)
PBARHI	Nominal average pressure (psia) from time = zero to TBHI
PULT	Design ultimate pressure (psia)
PYIELD	Design yield pressure (psia)
RBBAR	Burn rate (in/sec) at PBARHI pressure and with rate model used for ballistic simulation
TBHI	Nominal burn time (sec) from time = zero to time during tail-off corresponding to 99.5% propellant weight consumed at high temperature simulation
TBMIN	Lower three-sigma burn time (sec) calculated from TBHI

TABLE 35

OUTPUT OF PERFORMANCE COMPARISON WITH REQUIREMENTS AT LOW TEMPERATURE

Parameter Name	Definition and Units
FBARLO	Nominal average thrust (lbf) from time = zero to TBLO
FIGMIN	Lower three-sigma ignition thrust (lbf), at first time point in ballistic simulation at low temperature
ISPLO	Specific impulse (lbf-sec/lbm) at low temperature
ITMIN	Lower three-sigma total impulse (lbf-sec)
OBJFMN	Penalty for ignition thrust FIGMIN less than minimum limit (FMIN)
OBJIT	Penalty for total impulse ITMIN less than minimum limit
OBMAMX	Penalty for maximum Mach number in propellant cavity greater than maximum limit (MACLIM)
OBTBMX	Penalty for burn time TBMAX greater than maximum limit (TBMXLM)
PBARLO	Nominal average pressure (psia) from time = zero to TBLO
PIGN	Upper three-sigma ignition pressure (psia) at first time point in ballistic simulation at low temperature
RBBAR	Burn rate (in/sec) at PBARLO pressure and with rate model used for ballistic simulation
TBLO	Nominal burn time (sec) from time = zero to time during tail-off corresponding to 99.5% propellant weight consumed at low temperature simulation
TBMAX	Upper three-sigma burn time (sec) calculated from TBLO

TABLE 36

OUTPUT OF PERFORMANCE COMPARISON WITH REQUIREMENTS AT SINGLE TEMPERATURE

Parameter Name	Definitions and Units
FBAR	Nominal average thrust (lbf) from time = zero to TB
FIGMAX	Upper three-sigma ignition thrust (lbf), at first time point in simulation
FIGMIN	Lower three-sigma ignition thrust (lbf), at first time point in ballistic simulation
ISP70	Specific impulse (lbf-sec/lbm)
ITMIN	Lower three-sigma total impulse (lbf sec)
MEOP	Maximum expected operating pressure (psia), maximum nominal head-end pressure at high temperature plus three-sigma statistical variation
OBJFMN	Penalty for ignition thrust FIGMIN less than minimum limit (FMIN)
OBJFMX	Penalty for ignition thrust FIGMAX greater than maximum limit (FMAX)
OBJIT	Penalty for total impulse ITMIN less than minimum limit (ITREQ)
OBMAMX	Penalty for maximum Mach number in the propellant cavity greater than maximum limit (MACLIM)
OBPMAX	Penalty for maximum nominal head-end pressure (PH) during ballistic simulation greater than maximum limit (PHMAX)
OBTBMN	Penalty for burn time TBMIN less than minimum limit (TBMNLM)
OBTBMX	Penalty for burn time TBMAX greater than maximum limit (TBMXLM)
PBAR	Nominal average pressure (psia) from time = zero to TB
PULT	Design ultimate pressure (psia)
PYIELD	Design yield pressure (psia)
RBBAR	Burn rate (in/sec) at PBAR pressure and with rate model being used for ballistic simulation

Table 36

OUTPUT OF PERFORMANCE COMPARISON WITH REQUIREMENTS AT SINGLE TEMPERATURE (contd.)

Parameter Name	Definitions and Units
TB	Nominal burn time (sec) from time = zero to time during tail-off corresponding to 99.5% propellant weight consumed
TBMAX	Upper three-signa burn time (sec) calculated from TB
TBMIN	Lower three-sigma burn time (sec) calculated from TB

NOZZLE ANALYSIS RESULTS

This block of the code consists of output only and is the result of thermal and structural analyses of the selected nozzle configuration.

If a contoured nozzle exit selection is specified by the user (CONTUR= T and ALFA ≠ ALFAEX), this subroutine selects the contour (parabolic, hyperbolic or elliptical) giving the shortest overall nozzle length.

Results listed on Table 1, Nozzle Geometry, of the output are illustrated in Figures 64 and 65.. On Table 2, Operating Conditions, chamber pressure is MEOP and burn time is the burn time calculated from the low temperature simulation. Table 3, Insulation Design, gives the results of the thermal analysis. The column labeled "Insulation Weight" is the weight of the insulation element between Station I and Station (I-1). In Table 4, Nozzle Structure Design of the output, the following holds

Material	Designation of which structural material is at specified station.
Pressure	Static pressure (psia) at specified station.
F(X)	Axial force (lbf) acting on the nozzle, cumulative from exit plane. Positive aft.
PxR	Local static pressure (psia) times local radius (in) of inside surface.
Thickness	Thickness (in) of structural material at specified station.
Struct. Wt.	Weight (lbm) of element bounded by Station I and Station (I-1).
Criteria	Criteria by which structure thickness was established

HOOP	Hoop stress
SHEAR	Shear stress
BUCK	Buckling stress
LONG	Longitudinal stress
FAB	Minimum fabrication thickness

The criteria requiring the maximum thickness governs.

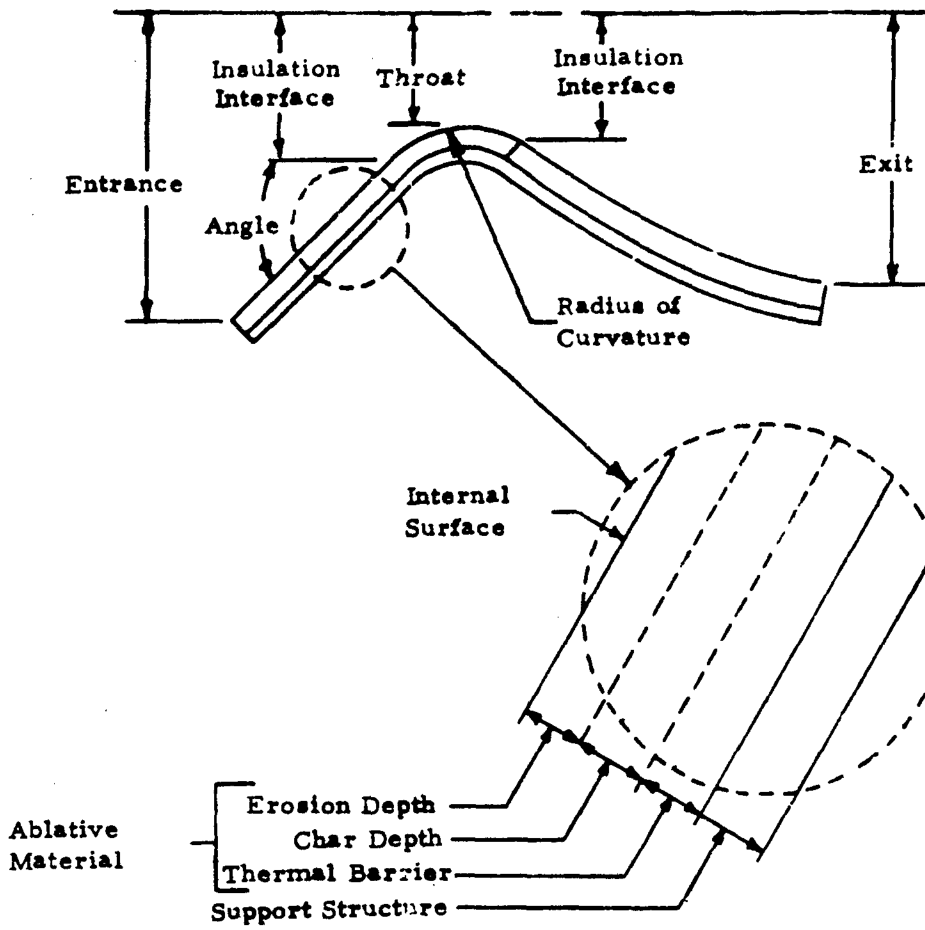
Cumulative Wt.	Cumulative weight (lbm) from the nozzle entrance.

TABLE 37

OUTPUT OF NOZZLE ANALYSIS SUBROUTINE

Parameter Name	Definition and Units
DBTO	Outside diameter (in) of blast tube Nozzle Type 4, 5 and 6.
LBT4	Length (in) of blast tube on Nozzle Type 4.
OBBTO5	Penalty for outside radius of blast tube (RBTO) exceeding input limit (DBTO5/2.0) for Nozzle Type 5.
OBBTO6	Penalty for outside radius of blast tube (RBTO) exceeding input limit (DBTO6/2.0) for Nozzle Type 6.
OBEXIM	Penalty for margin of insulation (EXINSM) less than zero at exit plane of Nozzle Types 3, 4 and 5.
OBJDEO	Penalty for outside radius of nozzle exit cone (RAO) exceeding input limit for Nozzle Types 1, 2, and 6. Limit is equal to (NTMR)(RMOTOR).
OBLBT4	Penalty for length of blast tube (LBT4) on Nozzle Type 4 not equal to requirement (LBT4RQ).

All other outputs are self-explanatory or are shown in the accompanying illustrations (either in this section or in the preceding section that defined the nozzle inputs).



(Nozzle Type 1 Shown)

Figure 64. Nozzle Geometry Described in Output of Nozzle Analysis Routine

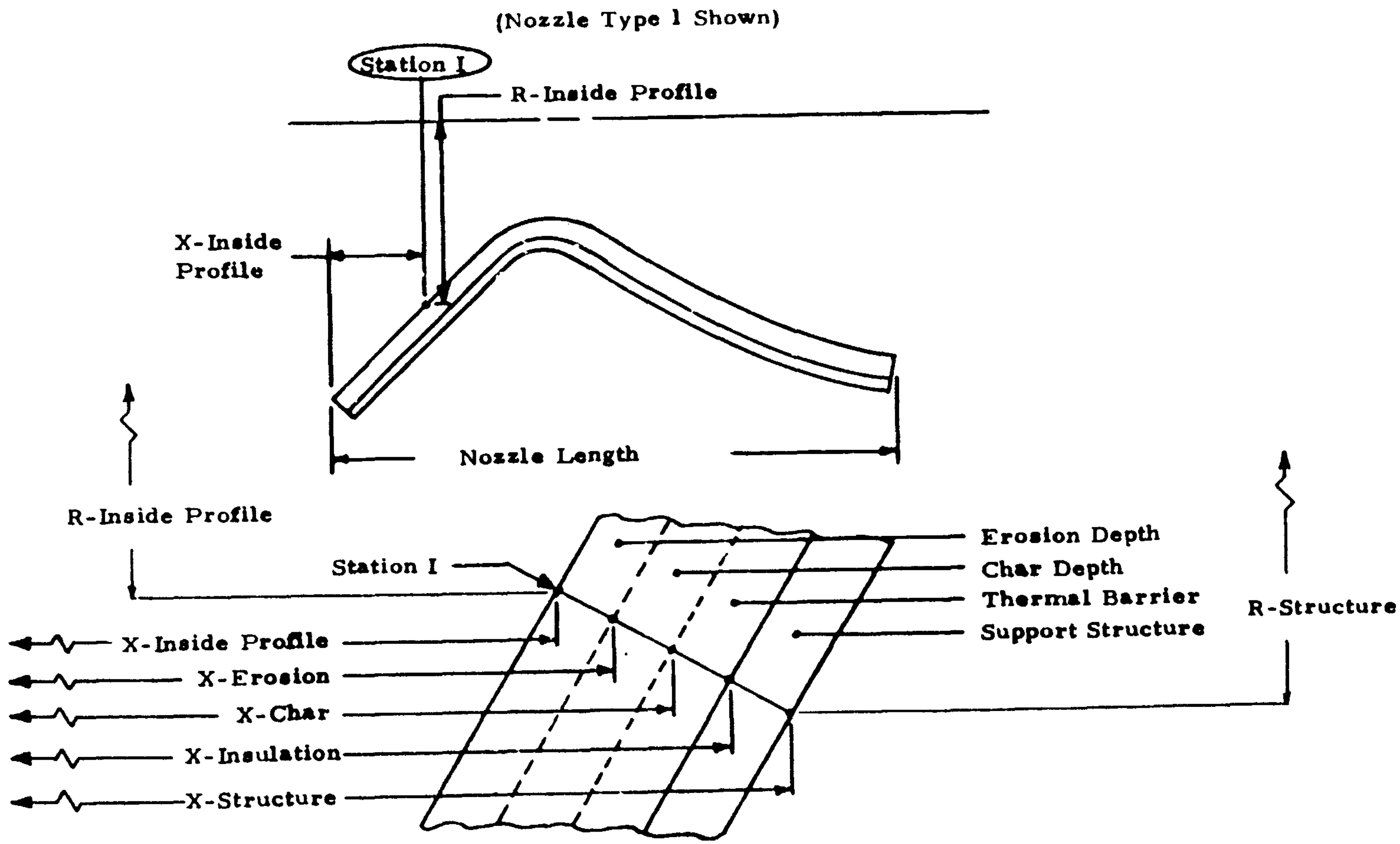


Figure 65. Nozzle Geometry Showing X-R Coordinates Described in Output of Nozzle Analysis Routine

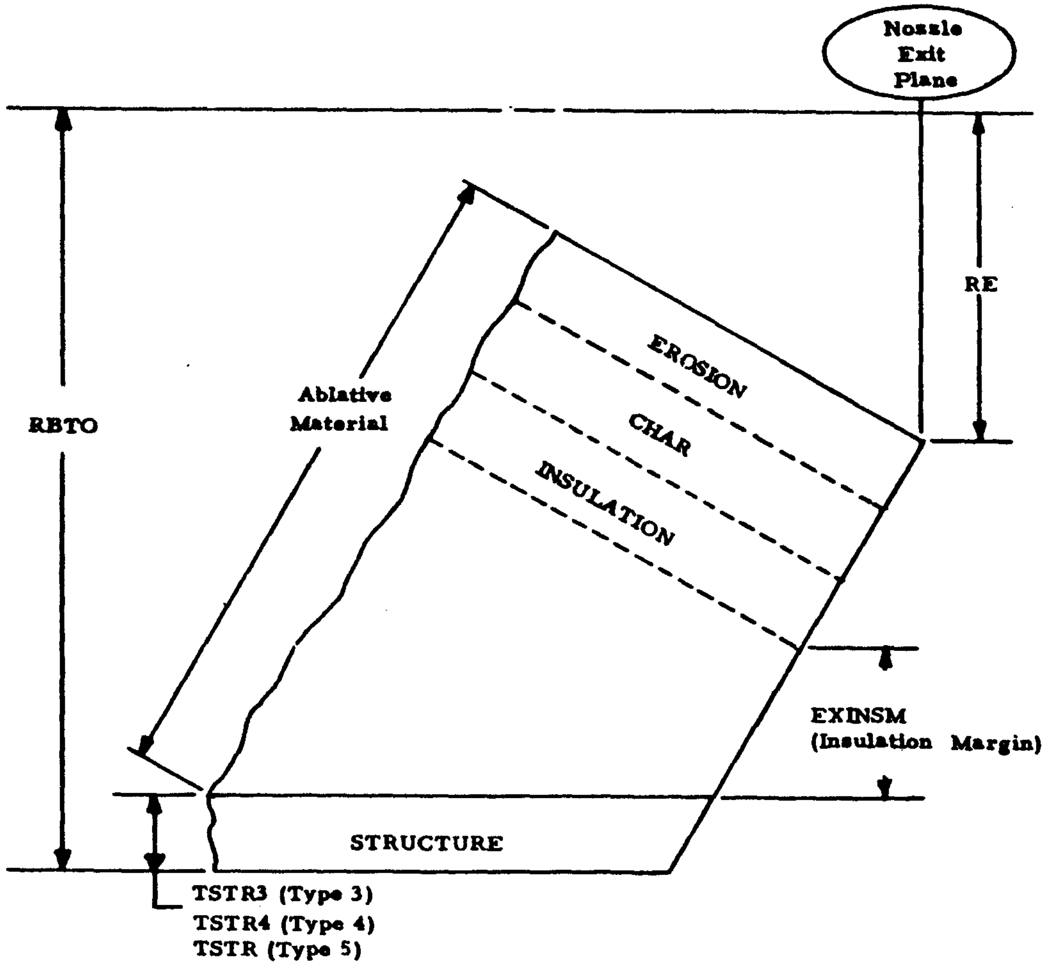


Figure 66. Insulation Margin at Exit Plane of Nozzle Types 3, 4 and 5

CASE STRUCTURAL ANALYSIS

This block of output contains the input data used for the case structural analysis (along with the design pressures resulting from the ballistic simulation) and the results of that analysis.

Also included in the output are all the weights associated with the pressure vessel (excluding nozzle) and the sum of all weights of motor inert components.

TABLE 38

NAMELIST/CASE

INPUTS FOR PRESSURE VESSEL STRUCTURAL ANALYSIS

Parameter Name	Default Value	Definition and Units
FTUC	Note 1	Ultimate tensile strength (psi) of case material[(2)].
FTYC	Note 1	Yield tensile strength (psi) of case material[(2)].
MODCAS	Note 1	Tensile elastic modulus (psi) of case material.
MODCLO	Note 1	Tensile elastic modulus (psi) of Type 2 forward closure material.
PRCAS	Note 1	Poisson's ratio of case material.
PRCLO	Note 1	Poisson's ratio of Type 2 forward closure material.

NOTES:

1. Input required for all problems.
2. Strength in "Hoop" direction.

TABLE 39

OUTPUT OF CASE STRUCTURAL ANALYSIS SUBROUTINE

Parameter Name	Definition and Units
OBJTC	Penalty for required case thickness (TCREQ) greater than current thickness (TCASE).
TCASE	Current thickness (in) of cylindrical portion of case.
TCLOA	Thickness (in) of aft closure required for current conditions.
TCLOF	Thickness (in) of forward closure required for current conditions.
TCREQ	Thickness (in) of cylindrical portion of case required for current design pressure (either ultimate or yield) and current motor diameter.
WCASE	Weight (lb) of pressure vessel.[1]
WCASCY	Weight (lb) of cylindrical portion of case.
WCLOA	Weight (lb) of aft closure.
WCLOF	Weight (lb) of forward closure.
WFLGA	Weight (lb) of case-to-nozzle attachment flange.
WINERT	Weight (lb) of all motor inert components.[2]
WSKTA	Weight (lb) of aft thrust skirt
WSKTF	Weight (lb) of forward thrust skirt.

NOTES

1. WCASE = WCASCY + WCLOF + WSKTF + WCLOA + WSKTF + WFLGA
2. WINERT is sum of all inert weights associated with motor (case, liner, insulation, stress-relief boots, nozzle, other).

PROPELLANT STRUCTURAL ANALYSIS

This block of output contains the input data used in the propellant structural analysis (along with pressures and grain dimensions resulting from previous calculations) and the results of that analysis.

TABLE 40

NAMELIST/STPROP

INPUTS FOR PROPELLANT STRUCTURAL ANALYSIS

Parameter Name	Default Value	Definition and Units
AGE	0.0	Fraction of original nominal propellant strain endurance capability lost as a result of aging degradation.
ALPHAC	Note 2	Coefficient of thermal expansion (in/in/°F) of pressure vessel. See Note 2.
ALPHAP	5×10^{-5}	Coefficient of thermal expansion (in/in/°F) of propellant. See Note 1.
CVPS	0.0	Coefficient of variation (% x 0.01) of propellant strain endurance.
EPPMX	1.0	Maximum allowed propellant strain due to ignition pressurization (in/in).
FSPS	1.0	Factor of safety applied to propellant strain.
MODPP	25000.	Tensile modulus (psi) of propellant under pressure loading. See Note 1.
MODPT	50.	Tensile modulus (psi) of propellant under thermal loading. See Note 1.
PRP	0.49	Poisson's ratio of propellant. See Note 1.
SEMDL	F	Propellant strain endurance model is supplied by user (T = yes, F = no).
SENOM	1.0	Nominal strain endurance (in/in) of propellant.
TPROP	155.0	Temperature (°F) at which propellant structural analysis will be performed. May be equal to or different from TLO, the low temperature at which ballistic simulation is performed.
TSF	155.0	Strain-free temperature (°F) above cure temperature at which cure shrinkage would be canceled. See Note 1.

NOTES:

1. Default values shown are typical for propellant.
2. Input required for all problems.

TABLE 41

OUTPUT OF PROPELLANT STRUCTURAL SUBROUTINE

Parameter Name	Definition and Units
EPP	Strain (in/in) in CP portion of grain Types 3, 4 and 5 induced by upper-three-sigma ignition pressurization at the low temperature.
EPPS	Strain (in/in) in slotted portions of grain Types 1, 2 and 3 induced by upper-three-sigma ignition pressurization at the low temperature.
EPT	Strain (in/in) in CP portion of grain Types 3, 4 and 5 induced by low temperature storage.
EPTS	Strain (in/in) in slotted portions of grain Types 1, 2 and 3 induced by low temperature storage.
MSP	Margin of safety in CP portion of grain for thermal strain in grain Types 3, 4 and 5, calculated from SEDES.
MSPS	Margin of safety in slotted portion of grain for thermal strain in grain Types 1, 2 and 3, calculated from SEDES.
OBEPP	Penalty for induced pressurization strain in CP portion of grain Types 3, 4 and 5 (EPP) greater than input maximum (EPPMX).
OBEPPS	Penalty for induced pressurization strain in slotted portion of grain Types 1, 2 and 3 (EPPS) greater than input maximum (EPPMX).
OBJPS	Penalty for margins of safety MSP less than zero.
OBJPSS	Penalty for margin of safety MSPS less than zero.
SEDES	Design strain endurance (in/in); nominal less three-sigma statistical variation less aging loss.
SIGPR	Intermediate parameter calculated for pressure strain evaluation. See Volume I for definition.
SIGTHM	Intermediate parameter calculated for thermal strain evaluation. See Volume I for definition.
H	Strain concentration factor used in Grain Types 1, 2 and 3 analyses. See Volume I for definition.

TRAJECTORY SIMULATION

This section of code output contains the inputs necessary for a trajectory simulation (FTRAJ=T in namelist CONTRL). The inputs are contained in four blocks (namelists) of data.

Namelist	Purpose
CTRAJ	Controls trajectory simulation
LAUNCH	Launch conditions
AERO	Aerodynamic data
TERM	Termination commands, may select from one of twelve.

There must be at least two points (e.g., Mach = zero and Mach = large) in the drag coefficient arrays, even though the input drag coefficient is zero.

Termination of the trajectory simulation will always occur at ground impact, regardless of the termination mode selected by the user. If the selected termination mode (or ground impact) is experienced prior to the end of motor operation, a penalty OBERLY is calculated (based on difference between termination time and motor burn time at low temperature); this approach makes the assumptions that the user-selected termination command has the correct magnitude and that motor operation subsequent to the time of interest in the trajectory (i.e., termination) is undesirable.

The user may select either a detailed printout of trajectory parameters at every time step, or a shorter summary listing of parameters that are used for evaluating the trajectory against user-input requirements.

If a two-temperature problem is being performed, whether or not a trajectory simulation is performed at both temperatures depends on the combination of trajectory-related performance requirements input in NAMELIST/REQMTS/. The following requirements must be different from their default values in order to achieve the noted results. See Table 27 for parameter definitions and Table 46 for penalty definitions.

Parameter	Default Value	Input different from Default value will Trigger trajectory at	Associated Penalty
DELVRQ	1.0	Low Temperature	OBJVRQ
TTTRQ	0.99E6	Low Temperature	OBJTTT
VTRQ	1.0	Low Temperature	OBJVTR
ACLIM	0.99E6	High Temperature	OBJACC

If a one-temperature problem is being run, all trajectory performance comparisons are made with results from the trajectory simulation with the single thrust history.

Ideal drag-free burnout velocity and axial acceleration are calculated in subroutine FLT if FTRAJ = F (its default value). Velocity at launch is assumed equal to zero. Burnout velocity is calculated and reported at both temperatures in a two-temperature problem, but the low temperature value is compared with the requirement (DELVRQ). Axial acceleration is calculated at high-temperature for comparison with its requirement (ACLIM).

The trajectory is divided into three segments. Phase I is during motor operation. Phase II is the coast period after motor burnout. Phase 0 is at the instant of motor burnout.

TABLE 42

NAMELIST/CTRAJ

INPUTS FOR TRAJECTORY CONTROL

Parameter Name	Default Value	Definitions and Units
FDELT1	20.	Number of integration steps to be used during motor burn time (Flight Phase 1). Integration step size equals TBURN/FDELT1.
FDELT2	20.	Multiplier on integration step size during motor burn time to determine integration step size during post-burn coast. Integration step size equals (TBURN/FDELT1) (FDELT2).
IATMOS	0	Integer to specify atmosphere model 0 1959 ARDC std 1 MIL-STD-210A Tropical 2 MIL-STD-210A Polar 3 MIL-STD-210A Hot 4 MIL-STD-210A Cold
IPRDET	0	Integer to specify amount of printout from trajectory subroutine 0 Minimum output (only at initial and termination points) 1 Maximum output (at every time step)

TABLE 43

NAMELIST/LAUNCH

INPUTS FOR TRAJECTORY LAUNCH CONDITIONS[(1)]

Parameter Name	Default Value	Definitions and Units
ALTAL	0.0	Missile altitude (ft) at launch.
FPAAL	0.0	Flight path angle (deg) at launch, measured from horizontal, positive up.
MACHAL	0.0	Missile Mach number at launch (Note 2).
RGFPAL	0.0	Range (ft) along the flight path from some arbitrary point at launch (Note 3).
RNGAL	0.0	Horizontal range (ft) from some arbitrary point at launch (Note 3).
VELAL	0.0	Missile velocity (ft/sec) at launch (Note 2).

[(1)] See Figure 67

[(2)] May input in the MACHAL or VELAL, but not both.

[(3)] These inputs allow user to control the origin of the range coordinate system. Launch need not occur at a range of zero.

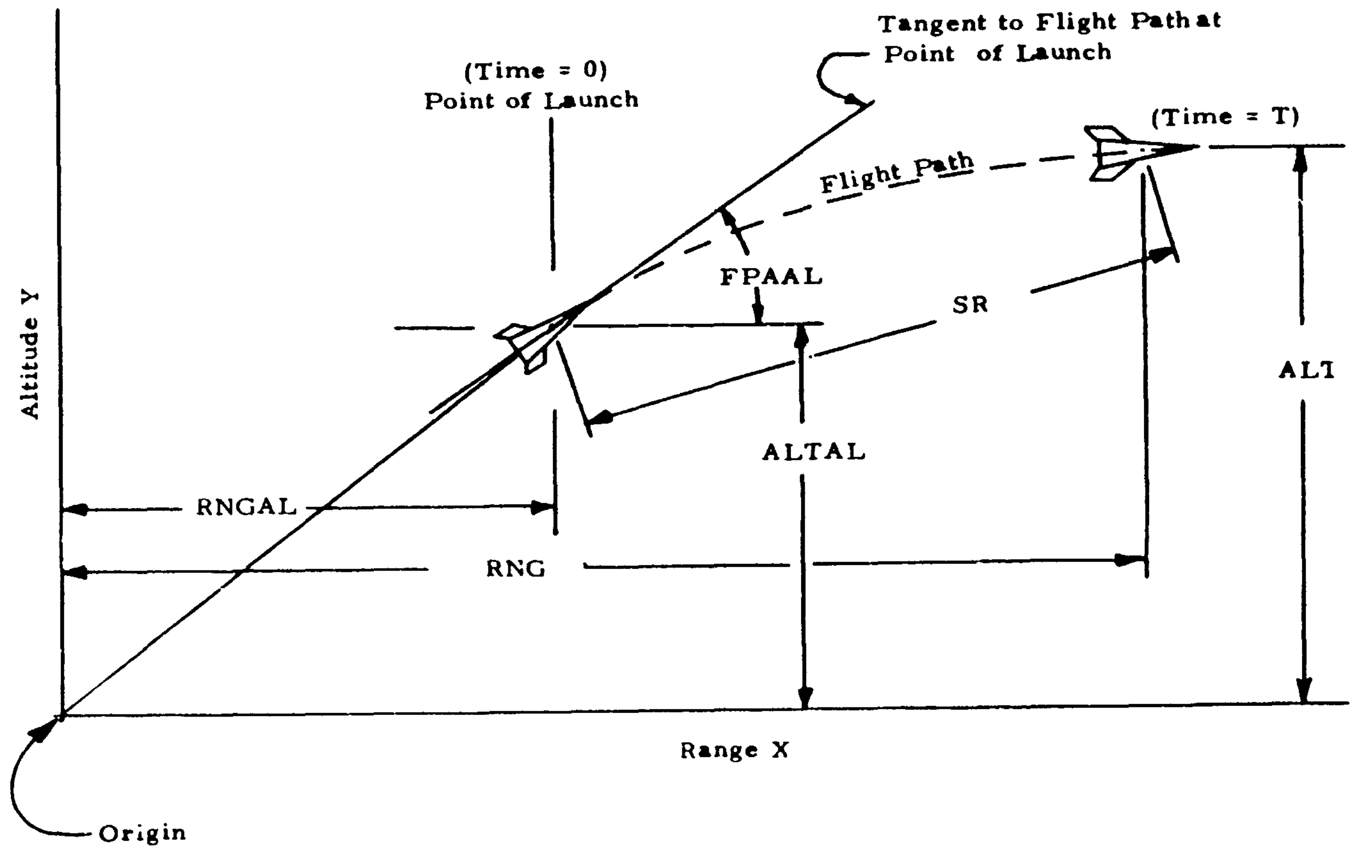


Figure 67. Trajectory Flight Path Nomenclature

Figure 67 (contd.)

$$RNG = RNGAL + \int_{O}^{T} VELX\, dt$$

$$ALT = ALTAL + \int_{O}^{T} VELY\, dt$$

$$RNGFP = RGFPAL + \int_{O}^{T} VELFP\, dt$$

The terms RNGAL, ALTAI, and RGFPAL are included to allow the user the capability to simulate missile launch at a point other than the origin of the altitude-range coordinate system. The flight path from the origin to the launch point is unspecified; thus the range along the flight path from origin to launch point (RGFPAL) must be specified.

The term SR is defined to be the slant range (i.e., line-of-sight range) from the launch point to the missile position at any time T.

The usual case is expected to be

$$\begin{aligned} RNGAL &= 0 \\ ALTAL &\neq 0 \\ RGFPAL &= 0 \end{aligned}$$

Thus RNG and RNGFP are measured from the point of launch. ALT is measured from sea level.

TABLE 44

NAMELIST/AERO

INPUTS FOR TRAJECTORY AERODYNAMIC INFORMATION

Parameter Name	Default Value	Definition and Units
AREF	0.0	Reference area (sq in) for missile aerodynamic drag coefficients.
NPOFF	2	Integer to specify number of points in table of missile power-off drag coefficients (25 maximum).
NPON	2	Integer to specify number of points in table of missile power-on drag coefficients (25 maximum).
TCDPOF	0.0, 0.0	Array containing values of missile power-off drag coefficients corresponding to Mach number TMPOFF.
TCDPON	0.0, 0.0	Array containing values of missile power-on drag coefficients corresponding to Mach number TMPON.
TMPOFF	0.0, 10.0	Array containing Mach numbers corresponding to power-off drag coefficients TCDPOF.
TMPON	0.0, 10.0	Array containing Mach numbers corresponding to power-on drag coefficients TCDPON.

NOTE: An array of Mach number and drag coefficients (power-on and power-off) of at least two members must be input for any trajectory simulation. Default values provide a zero-drag condition.

TABLE 45

NAMELIST/TERM

INPUTS FOR TRAJECTORY TERMINATION CONDITIONS

Parameter Name	Default Value	Definition and Units
ACTERM	0.0	Acceleration (g's) along missile flight path at which trajectory simulation will be terminated (ITERM = 9). Must be input as negative value. Test to determine if ACTERM has been reached is performed only after end of motor operation (Phase II) when missile acceleration is negative and is increasing (i.e., ACTERM is approached from below).
ALTERM	0.0	Altitude (ft) at which trajectory simulation will be terminated (ITERM = 5), which may be approached from above or from below. If termination altitude above the missile altitude, ALTERM should have positive sign; if termination altitude is below the missile altitude, ALTERM should have negative sign.
FPATRM	0.0	Flight path angle (deg) measured from horizontal at which trajectory simulation will be terminated (ITERM = 8). FPATRM will always be approached from above (i.e., missile flight path angle greater than FPATRM).
ITERM	12	Integer to control how trajectory simulation will be terminated.

ITERM	Termination Upon Achieving a Specified Value of
1	Total flight time
2	Phase 2 flight time (coast)
3	Slant range
4	Horizontal range
5	Altitude
6	Mach number
7	Velocity
8	Flight path angle
9	Acceleration
10	Ground Impact
11	Range along flight path
12	End of motor operation

Table 45

NAMELIST/TERM (Con:'d)

Parameter Name	Defalut Value	Definition and Units
MTERM	0.0	Mach number at which trajectory simulation will be terminated (ITERM = 6), which may be approached from above or below. If termination Mach number is greater than missile Mach number, MTERM should have positive sign; if termination Mach number is less than missile Mach number, MTERM should have negative sign.
RGFPTM	0.0	Range (ft) along flight path at which trajectory simulation will be terminated (ITERM = 11).
RGTERM	0.0	Horizontal range (ft) at which trajectory simulation will be terminated (ITERM = 4).
SRTERM	0.0	Slant range (ft) at which trajectory simulation will be terminated (ITERM = 3).
TERTIM	0.0	Flight time (sec) from launch at which trajectory simulation will be terminated (ITERM = 1).
TPHASE	0.0	Time (sec) from motor burnout (Phase 2) at which trajectory simulation will be terminated (ITERM = 2).
VLTERM	0.0	Velocity (ft/sec) along missile flight path at which trajectory will be terminated (ITERM = 7), which may be approached from above or below. If termination velocity is greater than missile velocity, VLTERM should have positive sign; if termination velocity is less than missile velocity, VLTERM should have negative sign.

TABLE 46

OUTPUT OF TRAJECTORY SIMULATION

INPUT SUMMARY

The first group of output is a summation of inputs, thrust table and propellant weight table.

Launch Conditions

FPAAL	Flight path angle (deg)
ALTAL	Altitude (ft
RGFPAL	Range along flight path from some arbitrary point (ft)
RNGAL	Horizontal range from arbitrary point (ft)
SRAL	Slant range from some arbitrary point (ft)
VELAL	Velocity (ft/sec). See Note 1
MACHAL	Mach number. See Note 1.

Missile Data

AREF	Missile aerodynamic reference area (sq in)
AEX	Nozzle exit area (sq in)
WNP	Non-propulsive weight (lbm)
WMI	Total missile inert weight (lbm); WNP + WINERT.

Controls

IATMOS	Atmosphere model
IPRINT	Basic code print command (internally controlled)
IPRDET	Control of print from trajectory analysis
FDELT1	Number of integration steps during powered flight
FDELT2	Coast integration step size, expressed as multiple of burn time integration step size

ITERM

Power-on Drag Coefficient Versus Mach Number

Power-off Drag Coefficient Versus Mach Number

Vacuum Thrust, Propellant Weight Remaining Versus Time

TIME-HISTORY OUTPUT

The second group of output is provided only when IPRDET = 1, which commands a detailed printout at each time point.

Parameter Name	Definition and Units
TIME	Time (sec) from motor ignition.
TDELT	Current value of numerical integration step size (sec).

Table 46

OUTPUT OF TRAJECTORY SIMULATION (contd.)

Parameter Name	Definition and Units
ACCABS	Missile absolute acceleration (ft/sec/sec); vector sum of all acceleration acting on missile, including gravity.
ACCFP	Missile acceleration (ft/sec/sec) along the flight path.
AX	Missile acceleration (ft/sec/sec) in horizontal (range) direction.
AY	Missile acceleration (ft/sec/sec) in vertical (altitude) plane .
FPA	Missile flight path angle (deg), measured from horizontal (positive up).
DENS	Ambient air density (slugs/cu ft).
SONV	Ambient sonic velocity (ft/sec).
IPHASE	Integer to indicate propulsion phase 0 Rocket has just burned out; TIME = BURN TIME 1 Rocket is operating 2 Coast flight
VELFP	Missile velocity (ft/sec) along flight path.
VELX	Horizontal (down range) component of flight path velocity (ft/sec).
VELY	Vertical component of flight path velocity (ft/sec).
MACH	Missile Mach number along flight path.
ROCFPA	Rate of change of flight path angle (deg/sec).
DRAG	Missile aerodynamic drag force (lb) along flight path.
IQDACC	Integer to indicate location of missile absolute acceleration vector. 1 First quadrant 2 Second quadrant 3 Third quadrant 4 Fourth quadrant

Table 46

OUTPUT OF TRAJECTORY SIMULATION (contd.)

Parameter Name	Definition and Units
ALT	Missile altitude (ft) from sea level.
RNG	Missile range (ft) from arbitrary zero reference; RNGAL plus range from launch point.
RNGFP	Missile range (ft) along flight path from arbitrary zero point.
SR	Slant range (ft) from launch point to instantaneous missile position.
ALPHAR	Absolute value of angle (radians) between missile absolute acceleration vector and the horizon.
DYNP	Dynamic pressure (lb/sq ft).
IQDVEL	Integer to indicate location of missile flight path velocity vector. 1 First quadrant (point above horizon) 4 Fourth quadrant (pointing below horizon)
WTMIS	Instantaneous total missile weight (lb).
WFR	Instantaneous remaining propellant weight (lb)
THRUST	Rocket motor thrust (lb) at flight altitude.
VACTST	Rocket motor vacuum thrust (lb).
CD	Missile drag coefficient (either power-on or power-off).
PAMB	Ambient pressure (psia).

SUMMARY OUTPUT

The third group of output is provided when IPRDET = 1 or 2 (i = 1 for Phase I flight, rocket motor operating, or i = 2 for Phase II flight, coast).

Parameter Name	Definition and Units
ACCMXi	Maximum missile acceleration (ft/sec/sec) along flight path occurring any time during indicated phase.

Table 46

OUTPUT OF TRAJECTORY SIMULATION (contd.)

Parameter Name	Definition and Units
ACCMNi	Minimum missile acceleration (ft/sec/sec) along flight path occurring any time during indicated phase.
VELMXi	Maximum missile velocity (ft/sec) along flight path occurring any time during indicated phase.
VELMNi	Minimum missile velocity (ft/sec) along flight path occurring any time during indicated phase.
ALTMXi	Maximum missile altitude (ft) occurring any time during indicated phase.
ALTMNi	Minimum missile altitude (ft) occurring any time during indicated phase.
MCHMXI	Maximum missile Mach number along flight path occurring any time during indicated phase.
MCHMNi	Minimum missile Mach number along flight path occurring any time during indicated phase.

PENALTY FUNCTIONS

Parameter Name	Definition and Units
OBJACC	Penalty for exceeding maximum flight path acceleration limit (ACLIM).
OBJDLV	Penalty for change in flight path velocity less than required (DELVRQ).
OBJTTT	Penalty for time to termination greater than required (TTTRQ).
OBJVTR	Penalty for termination velocity less than required (VTRQ).
OBERLY	Penalty for time of termination less than motor operating time.

NOTES

1. Either VELAL or MACHAL, but not both.

COST ANALYSIS

Motor costs can be estimated with the Tri-Services cost model (Reference 1) or through a user-supplied model. Input for the former are contained in subroutine CSTINP and calculations are in the subroutine MTRCST; input for the latter must be supplied as part of the user model, which is contained in subroutine USERCS. Both cost subroutines supply a value for the parameter COST.

COST will not be calculated unless the user specifies by setting FCOST=T. If the payoff parameter COST is selected for optimization (ICHOZE=1), the code internally sets FCOST=T, regardless of the user selection.

It is possible to obtain from the Tri-Services model estimates for development, PFRT, qualification and production costs, which are reported individually.

TABLE 47

NAMELIST/CSTINP

INPUTS FOR COST ANALYSIS

Parameter Name	Default Value	Definition and Units
ADDFAC[1]	0.0	Sum of additive cost factors for component cost adjustments, taken from Table 48 .
MULFAC[1]	1.0	Product of multiplicative cost factors for component cost adjustments, taken from Table 48 .
PFRT	T	Flag to specify PFRT costs to be calculated.
PRATE	0.0	Production rate (units per month). See Note 2.
PQUAN	0.0	Total production quantity (units). See Note 2.
QUAL	T	Flag to specify qualification costs to be calculated.

NOTES

1. User calculates factor product and sum of those adjustments listed in Table 48 that apply to problem.
2. If either PRATE or PQUAN are zero, only development, PFRT and QUAL costs are calculated.

TABLE 48

PRODUCTION COST FACTORS

Adjustment	Factor
o Case Attachments	
Forward attachment to missile	1.11
Launch lugs, aft of pressure vessel	1.07
Launch lugs, on pressure vessel, integral	1.13
Launch lugs, on pressure vessel, strap-on	1.07
Fin attachment, dovetail, untapered	1.20
Fin attachment, dovetail, tapered	1.30
Fin attachment, folding	1.25
Fin clips, fixed	1.07
o Blast tube	1.09
o Canted nozzle	1.05
o Grain	
Dual thrust, single grain	1.04
Composite smoky	1.00
Composite reduced smoke	0.98
Double base smoky	1.28
Double base minimum smoke	1.44
Dual thrust, dual grains	1.12
High burn rate, greater than 1.5 in/sec	1.12
High burn rate, greater than 3.0 in/sec	1.30
Free standing grain, internal burning	0.80
Free standing grain, internal/external burning	0.80
o Inert slivers	1.07
o External insulation	1.05
o Thrust vector control	
Liquid injection TVC	1.30
Flexible nozzle	1.40
Hot gas bleed	1.40
Warm injection and jet interaction	1.30
Jet vanes	1.35
Jet tabs	1.37

Table 48

PRODUCTION COST FACTORS (contd.)

Adjustment			Factor
o	Boost/Sustain		
		2:1 through 5:1	1.04
		6:1	1.06
		7:1	1.08
		8:1	1.10
		9:1	1.14
		10:1	1.20
o	Pulse Mode		
	One	One pulse (two grains)	1.33
		Two pulse (three grains)	1.64
		Four pulse (five grains)	1.80
o	Thermal cookoff		1.04
o	Thrust termination		
		Propellant extinguishment	1.09
		Thrust reversal	1.13
o	Wire harness		1.09
o	RI filter		1.04
o	Igniter (additive)		$336
o	Safe/arm (additive)		
		Manual	$462
		Remote	$2217

TABLE 49

OUTPUT OF COST ANALYSIS SUBROUTINE

Parameter Name	Definition and Units
AUPCST	Average unit production cost ($/unit).
BFUCST	Base first unit production cost ($/unit).
COST	Total project cost ($). Development, PFRT, qualification, production.
DEVCST	Development program cost ($).
FUPCST	First unit production cost ($/unit).
ISP	Delivered specific impulse, 70°F (lbf-sec/lbm).
MF	Motor mass fraction.
PFRTCS	Pre-flight readiness tests (PFRT) program cost ($).
PRATEF	Learning curve factor for production rate.
PQUANF	Learning curve factor for production quantity.
QUALCS	Qualification program cost ($).
TPCST	Total production costs ($).
WMOTOR	Motor weight (lbm).

COMBUSTION STABILITY ANALYSIS

A combustion stability analysis will be performed if input FSTAB of namelist CONTRL equals T. The analysis will be performed at internally specified fractions of propellant weight burned, nominally every five percent for printed outputs.

The combustion stability analysis used is a modification of the one-dimensional longitudinal Standardized Stability Prediction (SSP) (Ref. 1) which is tailored for reduced run time. The analysis requires inputs for 1) control, 2) geometry, 3) ballistics, 4) thermochemical data, 5) propellant ingredients, and 6) response functions. All inputs for geometry, ballistics, thermochemistry and ingredients are transferred internally via common statements from the generating subroutines. Most control options have been fixed internally or excised from the analysis code. The single remaining control option input is the number of modes to be analyzed. An input option has been added to specify the type model to be used for the propellant combustion response. These two options and the necessary response function input data may be entered by the user in namelist STABIN. However, as default conditions have been provided, it is not required that any entry be made in namelist STABIN if the defaults are acceptable to the user.

The output from this block of the code includes a listing of all input data (including data transferred through Common), various diagnostic messages, and results of the stability analysis. As this analysis was derived from SSP, most of the parameter names (both internal and external) will be familiar to SSP users.

Combustion response models number 3 and number 4 require ammonium perchlorate (AP) concentration and size (s). These data are furnished through the namelist INGAMT, which is read if either FORMAD = T or FORMIN = T (in namelist CONTRL).

TABLE 50

NAMELIST/STABIN

INPUT FOR COMBUSTION STABILITY ANALYSIS

Parameter Name	Default Value	Definition and Units
NMODE	4	Number of acoustic normal modes to be analyzed for stability. 1 ≤ NMODE ≤ 20.
IRSPNS	4	Control to specify propellant combustion response model. 1 ≤ IRSPNS ≤ 4 (5 if user-supplied model inserted in subroutine RSPNSE). See Note 1.
FRES(N)	Note 2	Frequency (Hz) used as abscissa for interpolation at mode frequency (if IRSPNS = 1) for RPLAT, RPEND, RV. (N = 1,2,3,---9). Must monotonically increase!
RPLAT(N)	0.	Pressure-coupled propellant combustion response at FRES(N) for lateral surfaces. 1 ≤ N ≤ 9
RPEND(N)	0.	Pressure-coupled propellant combustion response at FRES(N) for end surface. 1 ≤ N ≤ 9
RV(N)	0.	Velocity-coupled propellant combustion response at FRES(N) for lateral surfaces. 1 ≤ N ≤ 9
RFT	-1.	Flow turning response, constant with frequency, for lateral surfaces. (must be negative for loss)
RN	-(1.+GAMMA)/2.	Nozzle response, constant with frequency. (GAMMA supplied via Common) (must be negative for loss).
APARAM	0.	Parameter 'A' in analytical combustion response model.
BPARAM	0.	Parameter 'B' in analytical combustion response model.
DFUSVT	0.	Effective thermal diffusivity (in^2/sec) used to calculate dimensionless frequency in analytical combustion response model.

Table 50 (cont'd)

NOTES:

(1) IRSPNS values permitted.

1	Specifies direct input combustion response. Interpolates RPLAT, RPEND, and RV at each mode frequency with abscissa FRES.
2	Specifies analytical combustion response model due to Culick. Requires inputs are APARAM, BPARAM and DFUSVT.
3	Specifies empirical combustion response model due to Cohen.
4	Specifies empirical combustion response model due to Hessler.
(5)	If user-specified model is desired, insert the model code in subroutine RSPNSE and change the tests in subroutines RSPNSE and INPUT.

Values for IRSPNS of 3 and 4 require internal transfer of the AP oxidizer size data. Consequently, the AP size data must be specified in namelists NAMING and INGAMT.

(2) FRES = 1.0, 3.0, 10.0, 30.0, 100.0, 300.0, 1000.0, 3000.0, 10,000.0.

TABLE 51

OUTPUT OF THE COMBUSTION STABILITY ANALYSIS

INPUT DATA, CONSTANT IN TIME

The first block of output from the stability analysis consists of an echo of the input namelist STABIN, input diagnostic messages, a listing of selected internally transferred inputs, and a listing of selected control parameters. The user is referred to the STABIN input table for definitions of those inputs. This block of data is only printed during the initial call of the stability analysis.

MESSAGES

"NMODE UNSPECIFIED, ASSUMING 4" (Default condition.)
"IRSPNS UNSPECIFIED, ASSUMING 4" (Default condition.)
"FOR IRSPNS = 2, APARAM, BPARAM AND DFUSVT MUST BE NON-ZERO" (This condition not met, terminating.)
"IRSPNS OPTION UNDEFINED, TERMINATING" (User-supplied response option specified but not furnished.)

"BURNING RATE INPUTS:" KRI, KR2, KR3, KR5, KR6, SF inputs transferred internally from namelist BALLST

"EMPIRICAL RESPONSE FUNCTION INPUTS:" IMODES, CONCAP, DIAAP, CONCD inputs transferred internally from namelist INGAMT.

"DIRECT RESPONSE FUNCTION INPUTS:" FRES, RPEND, RPLAT, RV, RN, and RFT inputs specified in namelist STABIN.

"NMODE = " Value used in stability analysis

"ANALYTICAL RESPONSE FUNCTION INPUTS: " APARAM, BPARAM, DFUSVT inputs specified in namelist STABIN

"NTIMES = " Internally transferred input specifying the number of timepoints to be analyzed during burn.

"NSEC = " Internally transferred input specifying the number of cylindrical or conical sections used to describe the motor acoustic cavity.

"NNOZ = " Internally transferred input specifying the section at the downstream end of which the nozzle is located.

"IRSPNS = "Combustion response option used for stability analysis.

Table 51

OUTPUT OF THE COMBUSTION STABILITY ANALYSIS (contd.)

INPUT DATA, TIME-VARIABLE

The second block of output from the stability analysis consists generally of data that varies with time. However, to retain similarity with the SSP format, some constant inputs are repeated here. This block of output is printed at the start of each new time point, listing the inputs used for the stability analysis at that time point.

Output Symbol	Fortran Symbol	Definition and Units
'OVERALL1'	N/A	Propellant and gas properties
'PBARH'	N/A	Head-end pressure (psia)
'VT'	N/A	Set equal to threshold Mach number KR3
VISCOSITY	XMU	Viscosity ($lb\text{-}sec/in^2$)
PRANDTL	PR	Prandtl number.
CP(GAS)	CP	Specific heat at constant pressure (cal/gm/K)
DENSITY	RHOPR	Propellant density ($lb\text{-}sec^2/in^4$)
GAMMA	GAMMA	Specific heat ratio of combustion products.
'NBD'	N/A	Nozzle boundary condition, defined by coding to be UHAT = 0.
'OVERALL2'	N/A	Acoustic mode search parameters
FINITIAL	F0	Initial frequency of search (Hz).
DELTAF	DF	Search frequency increment (Hz).
FMAX	FMAX	Final frequency of search (Hz).
UTOL	UAZERO	Convergence criterion (in/sec)
NUMBER	I	Section number (NSEC lines of output).
LENGTH	XL(I)	Section length
FOR	S(1, I)	Cross-sectional (port) at forward end of section I.
AFT	S(2, I)	Cross-sectional (port) area at aft end.
LATERAL	SBL(I)	Lateral burning surface area.
FOR	SBE(1, I)	End-burning surface area at forward-end.
AFT	SBE(2, I)	End-burning surface area at aft end.
FOR	Q (1, I)	Burning perimeter at forward end.
AFT	Q(2, I)	Burning perimeter at aft end.
SPEED	A(I)	Speed of sound in section I (in/sec).
SECTION	I	Section number (NSEC lines of output).
XLL	XLL (I)	Length from head end to end of section I (in).
RBAR	RBAR(I)	Average burn rate in section I (in/sec).

Table 51

OUTPUT OF THE COMBUSTION STABILITY ANALYSIS (contd.)

Output Symbol	Fortran Symbol	Definition and Units
PBAR	XPBAR(I)	Average static pressure in section I (psia).
MACH	XMACH(I)	Average Mach number in section I.
RHO	RHO(I)	Average gas density in section I.
ENP	ENP(I)	Pressure exponent.
EN0	EN0 (I)	Pressure exponent with zero crossflow.
ENU	ENU(I)	Velocity exponent.

OUTPUT DATA

The third block of output from the stability analysis consists of a listing of the combustion response values and the portions of the stability integrals for each section of the acoustic cavity and listings of the time, longitudinal mode number, mode frequency and stability margin for that mode. This block is repeated NMODE times for each time point.

Output Symbol	Fortran Symbol	Definition and Units
TIME	TTIME(K)	Time during burn at which analysis was performed (sec).
MODE	J	Longitudinal mode number.
FREQUENCY	F	Frequency of Jth mode.
IRSPNS	IRSPNS	Combustion response option used.
I	I	Section number.
ARPL	ARPL(I)	Lateral-surface pressure-coupled response for the Ith section at the Jth mode frequency.
ARPE	ARPE(I)	End-surface pressure coupled response.
ARV	ARV(I)	Velocity-coupled response
DAPL	DAPL(I)	Increment of lateral-surface pressure-coupled stability integral for the Ith section, Jth mode.
DAPE	DAPE(I)	Increment of end-surface pressure-coupled stability integral.
DALV	DALV(I)	Increment of velocity-coupled stability integral.
DAFT	DAFT(I)	Increment of flow-turning stability integral.
(IPCEND*RPEND)		The sum for all NSEC sections of the product of ARPE*DAPE for the Jth mode: the total end-surface pressure-coupling gain.

Table 51

OUTPUT OF THE COMBUSTION STABILITY ANALYSIS (contd.)

Output Symbol	Fortran Symbol	Definition and Units
(IPLAT*RPLAT)		Sum of ARPL*DAPL: lateral-surface pressure coupling gain.
Number*RFT		The number is the flow-turning stability integral. This indicated product is the flow-turning loss (loss since the input RFT must be negative).
(ILNVC*RV)		Sum of ARV*DALV: Velocity coupling gain (or loss if negative).
Number*RN		The number is the nozzle-loss stability integral. The indicated product is the nozzle loss (since the input RN must be negative).
(PARTICLE DAMPING)		Particle damping is not calculated, but would be entered here if it were.
ALPHA	AL	Alpha is the sum of the gains and losses. Its calculated value is printed as 'the total calculated linear alpha' just below. A positive value indicates instability is predicted for the Jth mode at TTIME(K). A negative value indicates stability for the Jth mode at TTIME(K).
H	H	H = -ALPHA(J,K)/F(J,K)
STABILITY PENALTY	OBSTAB	The penalty is calculated for the minimum value of H (HMIN) calculated for all (J,K). The value is printed at the end of the third output block for the last mode at the last time. See Vol. I for complete definition.

SUMMARY OUTPUT

This section of code output provides summary information.

First, under the heading of "Trajectory Simulation", there are ideal drag-free burnout velocity and acceleration.

Then, under the heading of "Summary Data", there are several overall measurements of motor characteristics and the final objective function.

The last two tables give information about the adjusted parameters.

TABLE 52

IDEAL TRAJECTORY SIMULATION

Parameter Name	Definition and Units
ACLMAX	Maximum axial drag-free acceleration (g)
OBACMX	Penalty for exceeding maximum limit acceleration (ACLIM)
OBJVBO	Penalty for ideal burnout velocity less than requirement (VBORQ)
VBOHI	Ideal burnout velocity (ft/sec) resulting from high temperature simulation
VBOLO	Ideal burnout velocity (ft/sec) resulting from low temperature simulation

TABLE 53

SUMMARY DATA

Parameter Name	Definition and Units
CSTR70	Characteristic velocity (nozzle end) at 70°F (ft/sec)
DELP	Propellant cured density (lb/cu in)
DMOTMX	Maximum motor outside diameter limit (in)
DMOTOR	Motor outside diameter (in)
GAMAC	Ratio of specific heats in combustion chamber
ITMIN	Lower three-sigma total impulse (lbf-sec) at lowest ballistic simulation temperature
ITOWMO	Ratio of total impulse, ITMIN, to total motor weight, WMOTOR (lbf-sec/lbm)
LMOTMX	Maximum motor length limit (in)
LTOTAL	Total length (in) of motor
MF	Motor mass fraction (FUEL WEIGHT/WMOTOR)
OBJDMO	Penalty for exceeding maximum motor diameter limit (DMOTMX)
OBJLMO	Penalty for exceeding maximum motor total length limit (LMOTMX)
OBJWMO	Penalty for exceeding maximum motor total weight limit (WMOTMX)
PAYOFF	Numerical value of parameter selected for optimization as identified by the input ICHOZE
RB70	Propellant burn rate at 1000 psia, 70°F (in/sec)
RGAS	Gas constant of combustion products in chamber (ft-lbf/lbm-°R)
TOTAL OBJ	Sum of PAYOFF and TOTAL PENALTY
TOTAL PENALTY	Sum of all individual penalties

Table 53

Summary Data (contd.)

Parameter Name	Definition and Units
WINERT	Motor inert weight (lbm)
WMOTMX	Maximum motor weight limit (lbm). Propulsion unit only
WMOTOR	Total motor weight (lbm). Propulsion unit only.
XN	Pressure exponent in propellant burn rate model RB = A*P**XN where P = local static pressure (psia) RB = propellant surface regression rate (in/sec) A = constant coefficient

USER MODELS

Provisions have been made for the user to supply special mathematical models to describe certain characteristics of the motor. They are:

(1) Propellant burn rate
(2) Propellant nominal strain endurance
(3) Propellant rheological property
(4) Motor costs
(5) Impulse efficiency
(6) Combustion response

The procedure for employing a user-supplied model is as follows:

(1) In the subroutines that are furnished (Table 54).
   (a) Code the mathematical model, making sure the dependent variable has the nomenclature given in Table 54.
   (b) Add any common statements required to furnish the independent variables required by the model.
   (c) Furnish any WRITE commands that are needed to print information from the model. See further discussion below.
(2) Compile the subroutine and link with the remainder of the code.
(3) Set the flag in the namelists shown in Table 54 to show that a given user model is being furnished.

The internal flag of IPRINT is used to control when computation results are printed.

IPRINT = 1	All write statements are executed
IPRINT = 0	Only PATSH output is printed

Therefore, WRITE commands in the user-model subroutines should be structured such that they are executed when IPRINT = 1 and are branched around when IPRINT = 0.

If data must be supplied to the model by the user, a READ command must be included for a namelist defined by the user. Common TRIGR contains the flag IPRINT (discussed above) and a similar flag to read data (IREAD).

IREAD = 1	To read data
IREAD = 0	To bypass read command

IREAD = 1 only for first pass through COMP.
IPRINT = 1 for both the first and last passes through COMP.

TABLE 54

USER-SUPPLIED MODELS

Parameter to be Supplied	Flag to Call User Model Name	Input NL	Load Model In Subroutine
Propellant burn rate, RATE (in/sec)	RBMDL[1]	CONTRL	USERRB
Propellant nominal strain endurance, SENOM (in/in)	SEMDL[1]	STPROP	USERSE
Propellant rheological property, EOM (units by user)	EOMMDL[1]	INGLM	USERRH
Motor cost, COST ($ or $/unit)	CSTMDL[1]	CONTRL	USERCS
Impulse efficiency, ETAISP (% x 0.01)	EFMDL[1]	CONTRL	USEREF
Combustion response	IRSPNS[2]	STABIN	RSPNSE

(1) T = user model is furnished; F = internal model will be used.
(2) 5 = user model is furnished.

PROPELLANT BURNING RATE

The user-supplied propellant burn rate model must be installed in subroutine USERRB. The flag RBMDL = T must be input in namelist CONTRL so that USERRB will be called whenever burn rate must be calculated. The common statement /IB/ must be employed in subroutine USERRB, to furnish values for pressure (P), Mach number (MACH), and rate scale factor (SF) and to pass back the calculated burn rate (RATE). If the user wishes to identify which burn rate equation out of several possibilities is being employed in subroutine USERRB, the common statement /SEC3/ must be included to furnish the variable RATEQU; values for RATEQU will be printed out at time zero in the ballistic simulation for each plane along the grain.

The burn rate subroutine is called from subroutines HITEMP, LOTEMP and ONETMP with a pressure averaged over the ballistic simulations at high temperature, low temperature and single temperature, respectively. The purpose of the calculations at this point in the code is to obtain an average burn rate without cross flow effects to send to the SPP impulse efficiency model. Therefore, Mach number is not supplied from these subroutines, and a flag is set (IFLAG = 1) to mark where the call to the rate subroutine originated. Then, in the rate subroutine, IFLAG = 1 triggers a return to the calling routine after a non-erosive rate has been calculated. The user-supplied subroutine USERRB must contain this same response.

Other commons that already exist may be included in USERRB in order to furnish the data needed for the user model.

Burn rate at 70°F and 1000 psia (RB70) normally is compared with constraints (RBMAX and RBMIN) in subroutine COMP; input values for RB70, RBMAX and RBMIN are furnished in namelist BALLST. When USERRB is employed, RB70 = 0.0 must be input; and RBMAX and RBMIN must be allowed to default. Then, if the user so desires for a particular problem, values of RBMIN and RBMAX must be furnished as part of USERRB, associated penalties calculated, and then these penalties added to OBJ to update the total penalty. The variable OBJ is available in common statement DLIST.

Temperature effects on burn rate can be included through the use of TMPUR as temperature in the new model. The variable TMPUR, which is contained in the common statement MODELS, is equated to THI just prior to the high temperature ballistic simulation; it is then equated to TLO just before the low temperature simulation. Thus, TMPUR has the appropriate value at the time USERRB is called in the ballistic simulation.

The flag NTEMPS identifies the number of ballistic simulations to be performed during any one pass through COMP; it is initialized to NTEMPS = 2, indicating that simulations will be performed at both high and low grain temperatures (THI and TLO, respectively). If the user inputs THI = TLO (in namelist BALLST), NTEMPS is reset to one in COMP. Thus NTEMPS can be used as a flag in USERRB to control logic flow so that both one-temperature and two-temperature problems can be solved with a single version of USERRB. NTEMPS is available through common statement REQIR.

A typical user-supplied burn rate model incorporated into its USERRB subroutine is given in Volume I.

PROPELLANT STRAIN ENDURANCE

The user-supplied propellant strain endurance model must be installed in subroutine USERSE. The flag SEMDL = T must be input in namelist STPROP so that USERSE will be called out of subroutine PROPST. The model must furnish the nominal strain endurance (SENOM) for comparison with thermally induced strains. The nominal value is devalued for mix-to-mix variations and aging degradation in PROPST. SENOM is returned from USERSE through the calling argument.

If the model is not furnished, SENOM is a constant user-supplied input.

PROPELLANT RHEOLOGICAL PROPERTY

The user-supplied propellant rheology model must be installed in subroutine USERRH. The flag EOMMDL = T must be input in namelist INGLIM so that USERRH will be called out of subroutine TCHEM.

This parameter (EOM) must be defined by the user; it can be end-of-mix viscosity (hence EOM), shear stress, or any other measure of rheological characteristics. The intent is that this model be used when propellant ingredient concentrations are being adjusted, so that some control can be exercised on the propellant processibility. If the flag has been set (EOMMDL = T), the output of the model (EOM) is compared with an input maximum limit, and a penalty (OBJEOM) is calculated if the limit is exceeded. EOM is returned from USERRH through the calling argument.

MOTOR COST

The user-supplied motor cost model must be installed in subroutine USERCS. The flag CSTMDL = T must be input in namelist CONTRL so that USERCS will be called out of subroutine COMP. The model must furnish the parameter COST, which is used only as one of the payoff parameters. The units can be either total project cost or unit cost. COST is returned from USERCS through the common statement MISL.

IMPULSE EFFICIENCY

The user-supplied impulse efficiency model must be installed in subroutine USEREF. The flag EFMDL = T must be input in namelist CONTRL so that USEREF will be called out of subroutine COMP. If a user efficiency model is called, then the SPP model cannot be called (i. e., SPPETA = F is required). The model-furnished impulse efficiency then is used in the ballistic simulation. Efficiency is returned from USEREF through the calling argument.

COMBUSTION RESPONSE

The user-supplied combustion response model must be installed in subroutine RSPNSE, which is the subroutine where all internal models are located. Thus many sources of input data are already available. Entry to the model is statement number 500. The flag IRSPNS = 5 will cause the user-supplied model to be called.

Combustion response is returned through the common ALF already furnished.